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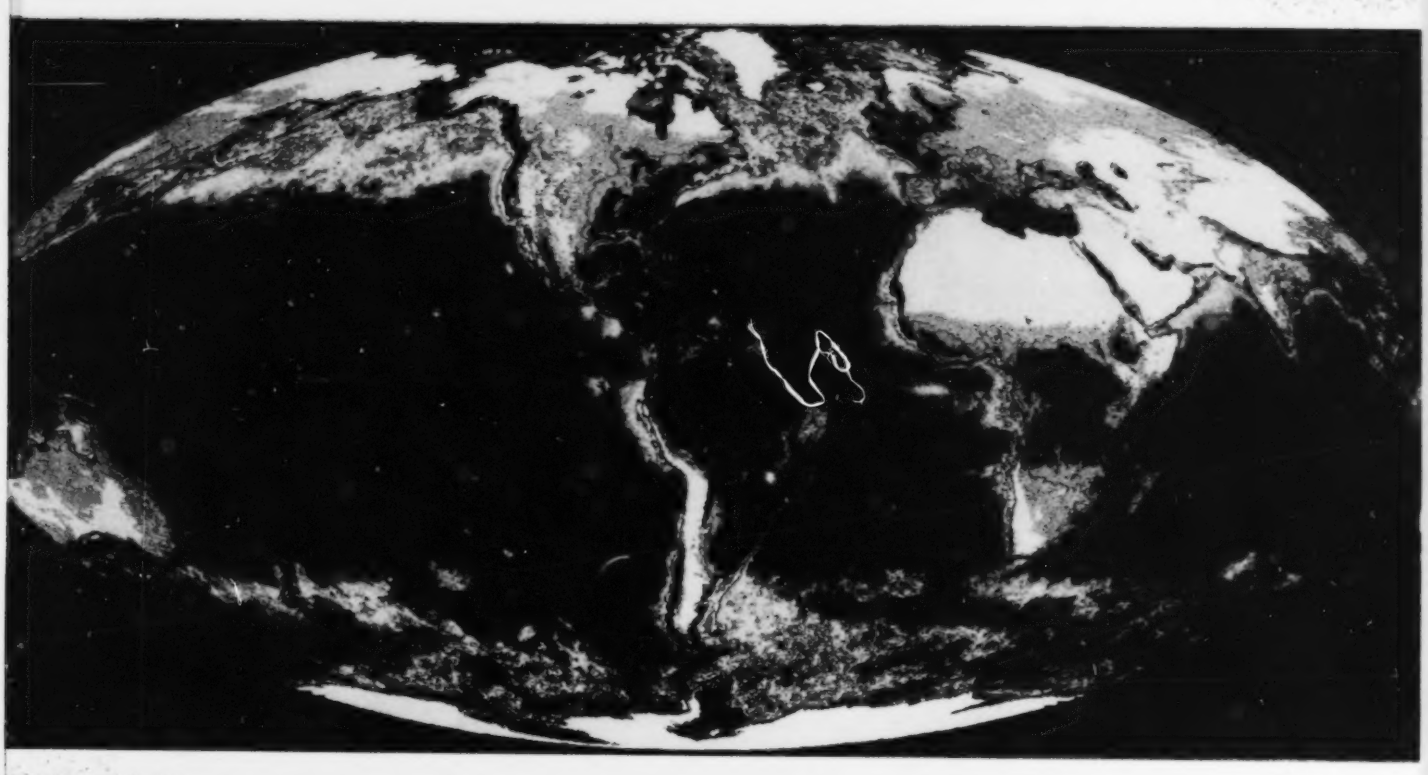
SEMINARS

of the United Nations Programme on Space Applications



Selected Papers on Remote Sensing,
Satellite Communications and Space Science
1993

United Nations

Office for Outer Space Affairs

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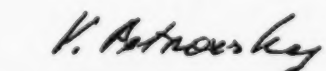
FOREWORD

Despite the dramatic improvement in the international political climate that has taken place over the past several years, the growing inequality of living standards among the countries of the world remains a growing threat to international peace and security. As part of a broad United Nations effort to assist developing countries in the utilization of space technologies for their economic and social development, the Office for Outer Space Affairs has in recent years emphasized the applications of space technology for economic and social development, environmental monitoring and disaster relief, as well as for building and rebuilding economic, social and environmental security and stability. This publication, the fourth in an annual series initiated in 1989, is part of the Office's programme of encouraging and facilitating the international exchange of information and experience which, along with other programmes and publications, promotes the United Nations goal of ensuring that outer space is used for exclusively peaceful purposes for the benefit of all countries.

Since 1972, the United Nations Office for Outer Space Affairs, as part of its programme on Space Applications, has organized and co-sponsored meetings, seminars, training courses and workshops on the application of space technology to assist developing countries in establishing an indigenous technological infrastructure and in developing and implementing local programmes. The Programme annually conducts activities devoted to various fields of space technology. In 1992 it organized activities dedicated to the use of remote sensing for environmental assessment and global change studies; development of indigenous capability at the local level in basic space science, and the various applications of satellite communications and remote sensing technology for geological sciences.

This publication is comprised of selected papers presented at the 1992 activities of the Programme on Space Applications that illustrate the issues relating to the use of space technology for management of natural resources and the environment. The scope of the publication extends from a general overview of the application of remote sensing technology for development to specific areas of applications, including the assessment of natural vegetation and agricultural systems and the use of space technology for rural education and development programmes. In examining the technology available for observing physical and biological processes and monitoring the environment, a number of papers focused on specific remote sensing techniques and instrumentation aboard the current generation of remote sensing satellites. Because the papers are selected from workshops, training courses and seminars held in various parts of the world, they address remote sensing applications corresponding to the specific needs of the regions concerned.



Vladimir Petrovsky
Under-Secretary-General for Political Affairs

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METHODOLOGIES AND SOFTWARE FOR SATELLITE IMAGE PROCESSING: USER NEEDS AND DEVELOPMENT TRENDS*

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INTRODUCTION

Growing concern for global environmental change, as expressed in the "Agenda 21" document of the United Nations Conference on Environment and Development (UNCED), make it necessary that tools such as satellite remote sensing should be used as efficiently as possible on two levels: for assessing and monitoring environmental changes on the global level and for managing natural resources on the local level. Change processes on the planetary scale are mostly being studied by extremely resourceful organizations with ample access to remote sensing equipment and expertise. Local environmental management must be conducted by institutions at the national or sub-national level. It is a far greater challenge to those involved in the development of methodologies and software for environmental remote sensing to produce models for useful applications of remote sensing on that level, taking into consideration the limited resources and expertise available. This is true in technologically highly developed countries, and even more so in developing countries.

This paper will mainly focus on how remote sensing techniques can come into practical use in the management of natural resources, especially in developing countries. The primary question that will be addressed is: What demands does this imply for the scientific, technical and organizational levels?

Initially, an attempt will be made to identify more precisely what are the de[illegible] of this group of users. Then current trends in remote sensing, image processin[illegible] computer technology will be briefly discussed. And finally some suggestions will be made concerning institutional arrangements for expanding the utilization of remote sensing methodologies in natural resources management in developing countries.

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* This paper, which was presented at the United Nations/IAF/ COSPAR/AIAA Symposium "Space Technology in Developing Countries - Making it Happen", held in Washington, D.C., United States, 28-30 August 1992, does not necessarily reflect the views of the United Nations.

NEEDS WITH REGARD TO DEVELOPMENT OF REMOTE SENSING METHODOLOGIES

The case for satellite remote sensing

Before discussing specific remote sensing methodologies and image processing algorithms a short discourse may be required, in order to identify user needs in a wider context, i.e. with regard to mapping and monitoring themes, to which remote sensing may contribute in a cost-efficient manner. The scientific literature contains a wealth of studies demonstrating the potential usefulness or (less often) uselessness of remote sensing techniques for a wide spectrum of applications, also with reference to developing countries. Relatively few of these are being used operationally in the management of natural resources. There are various reasons for this:

- Remote sensing techniques simply do not in all cases provide the information required in an operational context, even though the literature may claim it does. There is a long way between demonstration of the value of a certain remote sensing technique in a specific experiment and proving its reliability in a practical context. Also, scientists tend to "oversell" remote sensing methodologies.

- Relevant data provided by remote sensing techniques may be difficult to integrate with other "conventional" data and procedures in an existing system for management of natural resources.

- Some developing countries (and wealthy, industrialized countries as well) have insufficiently developed organizational frameworks for natural resources management, making them unable to demand, receive and utilize remote sensing data.

- The wealthy, industrialized countries, which possess the major part of the technological capacity within the remote sensing field, have not been particularly successful in finding ways of making these methodologies accessible to most countries in the developing world. Better models for cooperation are required.

Some development trends of remote sensing methodologies

Methodologies for processing and analyzing satellite remote sensing data are diverse, and it is difficult to make useful generalizations with respect to development trends. The following observations probably hold true, however:

1) Satellite images are to an increasing extent being integrated with other (often spatial) data, sometimes organized in "geographical information systems" (GIS).

2) The belief that more or less automatic procedures, such as multispectral classification methods, will replace manual/visual interpretation techniques gives way to a more balanced view, where manual/visual and computer-based methods supplement each other.

3) Conversion of raw satellite images into estimates of well-defined physical or biological parameters requires still more complex models of the entire measurement situation, including satellite/sensor-properties, the atmosphere, radiation-target interaction and the effects of spatial heterogeneity.

4) Remote sensing applications in natural resources management rely to an increasing extent on the use of time-series satellite images and on a combination of data from two or more satellite/sensor-systems.

Image processing hardware

Substantial development of image processing hardware has occurred in recent decades. In the 1970s satellite image processing was generally carried out on mainframe systems often with limited multispectral image display capabilities. Later, minicomputer-based systems became the standard. These were quite costly, which implied that they were used and managed by specialists, and "common users." Students generally had only limited access to these systems. In recent years personal computer (PC) and workstation-based image processing systems have taken over the market and prices on hardware have been decreasing fast. Very powerful "486" PC-based systems with full multispectral image display capabilities (32 bitplanes) may now be acquired at prices lower than $10,000. Storage media, such as hard-disks, magnetic tape and optical disks, have undergone similar developments, meaning that even full scenes of Landsat TM images, taking up almost 300 Mbytes, may be handled on PC-based systems. There is no reason to suggest that this development will slow down in the near future, because new and even more powerful processors will soon become available. Presently full-colour image display demands special display controllers. Yet some time within the next decade standard display systems of both PCs and workstations will attain the necessary quality (with respect to the number of bitplanes and the way they may be handled) allowing professional multispectral satellite image display. When this happens the current category "image processing system" will lose its meaning, hardware-wise. In most institutions computers either are or will soon become connected in networks. Image processing tasks requiring substantial computing-power will be conducted by the computer best suited for it in the network.

These technological and economic development trends have the consequence that image processing systems will (or at least should) be on the desktop of most potential users. This suggests that the number of users will increase considerably, if other bottlenecks do not slow down the development of these systems.

Operational and semi-operational remote sensing methodologies

In the past, attempts have been made to point out which remote sensing methodologies may be considered suitable for practical utilization. For a specific geographical area, the Sahel, Prince, Justice and Los have produced a useful review of methodologies, and in spite of the rapid changes within the field, most of their conclusions probably still hold true.1/ The following applications are labelled as ready for transition to operational use:

- Rainfall estimation
- Rangeland production monitoring
- Food security and early warning systems
- Bush-fire monitoring
- Ground water survey
- Land cover mapping

For other areas the set of operational methodologies may be slightly different, e.g. methods relying on optical satellite remote sensing are less suitable in more humid areas.

In the present context it may be just as relevant to point out methodologies which may not yet be ready for operational use but carry great potential. Prince et. al. discuss several methodologies requiring further development:2/

- Crop production monitoring and modelling
- Evapotranspiration estimation
- Hydrological catchment modelling
- Fuelwood estimation
- Erosion modelling and prediction

These lists of applications loosely define a set of requirements with regard to satellite image processing procedures and software.

Cost considerations

One topic seldom discussed in the scientific literature is the cost of applying the various methodologies suggested. Balancing costs and benefits is probably impossible within the field of environmental remote sensing, since the potential benefits, i.e. improved understanding of our environment, have no easily defined economic value, and the involved costs are highly intransparent. Cost assessments are therefore limited to comparisons between different remote sensing methods and between remote sensing methods and alternative means of data acquisition, and even this is often difficult. Major remote sensing applications in wealthy, technologically advanced countries are highly subsidized, and in many developing countries foreign donors finance almost all such activities. This may imply serious non-sustainability of remote sensing activities,

once subsidies or outside support disappear. To cope with this situation, a so called demand-driven approach to the development of remote sensing applications has been promoted.3/

However, certain remote sensing methodologies are basically inexpensive and no relevant alternatives can compete. It is suggested that the potential of these methodologies should be fully utilized by developing countries, possibly as a first step in the establishment of operational environmental satellite remote sensing activities, provided that the methodologies are suited for the area in question and that a certain information-demand exists. The use of meteorological satellite data, with high repetivity of coverage, large area-coverage and moderate cost, for monitoring of vegetation, crops, bush-fires and agroclimatic parameters is the best example of such a cost-efficient remote sensing methodology. Since it is also among those considered to be partly "operational" in a Sahelian context, there are good reasons to promote it.4/

Establishment and running of satellite image processing facilities is an important cost-component. In developing countries it is often extremely difficult to assure continuous functioning of complex computer-equipment, due to the lack of a technical back-up system, without costly outside assistance. Thus, there are good reasons for basing the application of remote sensing methods on the technology for which the need for technical back-up is smallest, i.e. PC-technology. It is often stated that more complex technologies, such as workstations, are better suited for image processing and GIS operations, and even though this may be true, the difficulties of service outweigh the advantages. Software-wise, the standard PC operating system, DOS, has considerable shortcomings in an image processing and GIS context. Yet, the alternative, UNIX, which is technically preferable, is so much more complex and requires so much more training that this again outweighs its advantages. New developments in the area of operating systems, such as OS2 or NT, will probably combine the relative simplicity of DOS with the technical advantages of UNIX.

THE USER COMMUNITY

The "typical" user

Precise pictures of the typical user of satellite remote sensing for natural resources management are difficult to produce, because the differences are enormous between and within countries. However, it is a widespread observation that remote sensing methods are slowly becoming tools used decentrally rather than merely objects of research dealt with by a few specialized institutions, and this has certain implications for the composition of the user community. Users are now more likely to be technicians and professionals whose main area of expertise is not remote sensing and image processing, but rather fields such as geography, geology, geophysics, biology, forestry or agricultural science. These users spend a minor fraction of their working hours doing satellite image processing, as compared to the remote sensing scientists who previously constituted the

majority of the user community. This is, of course, a natural and desirable development if one wishes to see remote sensing methodologies being utilized efficiently, yet it has a number of consequences for the character of the image processing methods and software to be applied:

- Image processing software must be integrated into methodologies and software used in practical natural resources management within a range of disciplines, rather than remain isolated in stand-alone systems. This will require an improved transparency and openness of the software.

- Users will typically require decision support when selecting methods and algorithms. This involves discipline, specific training materials, user-friendly interfaces, and possibly decision support systems/expert systems, assisting the user in finding optimal data-sources and processing procedures.

- Operational applications of remote sensing in natural resource management carried out by non-specialists of satellite image processing will require the minimization of the amount of human labour involved in the more technical image processing steps. For example, geometrical correction and co-registration of time-series of satellite images should be possible with little human involvement, yet without compromising accuracy.

Towards a hierarchy of users?

In some regions and for some data-sources it has been suggested that users be organized hierarchically. The "high level users" e.g. regional centres, would be responsible for certain preprocessing steps (including radiometric, atmospheric and/or geometrical correction) and production of derived data-sets. This may seem logical, because end-users would then not need to cope with the numerous and tedious processing steps involved, nor to possess precise knowledge on details of complex topics such as atmospheric correction algorithms. Such arrangements may evolve as a natural division of labour, beneficial to all levels in the hierarchy, or be imposed through monopolization of the data-flow. Monopolization may, however, seriously delay the development of practical applications of remote sensing in natural resource management, especially if the high-level user is a supra-national institution, while the management takes place on the national or sub-national level. In addition, monopolization of the flow of remote sensing data is probably unrealistic and undesired for other reasons:

- There are few computational and economic advantages of centralization within the field of satellite image preprocessing. In other words, reasonably well-equipped users will be able to carry out their own geometrical and radiometric preprocessing of images, and given the

widespread underutilization of computer capacity, it will be economically advantageous for them to do so.

- There are no widely accepted and generally applicable preprocessing procedures which will in the long run satisfy any end-user. Geometrical correction, carried out by institutions handling large data-volumes, tends not to live up to the standards required by some end-users, especially those using time-series of images. Thus, the reasonably advanced end-user will sooner or later also wish to have access to the raw data.

- In order to fully appreciate the information content, application potential and inherent limitations of remote sensing data, the user must be able to access the raw data, rather than, or in addition to, derive data-sets.

EXAMPLES OF REMOTE SENSING METHODOLOGIES AND SOFTWARE

Use of high-resolution optical satellite images for land-cover classification

Use of Landsat and SPOT-data for land-cover and land-use mapping and monitoring is becoming a standard methodology in regions where other data-sources are unreliable or absent. Methodologies vary considerably, yet in operational contexts visual interpretation techniques play an important role. The demands on satellite image processing methodologies and software, defined by this type of application, will be discussed below.

In Figure 1, the outlines of a sequence of image processing steps, typical for Landsat- or SPOT-based land-cover classification, are shown. The radiometric and geometrical correction procedures will not be discussed here; emphasis will be on how visual and computer-based analysis methods may be combined in order to utilize the analyst's prior knowledge of the area efficiently.

The "feature selection" and spectral transformation procedures aim at replacing the original image bands with new artificial ones, having desirable properties, such as:

1) Low correlations with other bands/features.
2) High content of relevant information or variance.
3) Simple interpretation, strong relations to interesting physical or biological parameters.

What demands on the image processing software does this feature selection imply? A non-exhaustive list will include:

- Efficient and flexible multispectral image display routines, allowing both automatic and manual, interactive contrast manipulation, since feature selection will often involve an element of subjective visual judgment.

- Routines for calculation of a variety of more or less complex indices, linear combinations, etc., on the basis of the original bands. These include simple ratios, standard vegetation indices and generally applied transformations, such as the "tasselled cap" transformation.

- A selection of multivariate statistical techniques, including principal components analysis, aiming at decorrelation of image bands.

- Methods for measuring the spectral properties and "separability" of a number of "classes", specified by the analyst. The success of various spectral transformations may be studied using such measures of separability.

The classification step may involve a mixture of visual interpretation and user-guided automatic classification. Standard classification algorithms, such as the "minimum distance" and "maximum likelihood" procedures, require the analyst to point out training areas, representative for each class, and the rest is left to the computer/algorithm. Results are often not satisfactory, since the analyst's full knowledge, as well as the non-spectral information in the image, are not utilized. Innumerable attempts have been made to refine classification techniques. Yet, in spite of many improvements, visual interpretation techniques are still preferable in many situations, especially where identification of spatial entities play a significant role. With respect to image classification software, this calls for procedures geared for interactive analysis, allowing efficient utilization of the analyst's expertise, rather than once-and-for-all classification algorithms. Simple, fast and flexible hierarchical procedures, as the one sketched in Figure 2, will probably support the analyst better than complex statistically-based methods.

The visual interpretation will usually be based upon a spectrally transformed image, as discussed above. In addition, it might be useful to enhance the image by suppressing noise and sharpening boundaries. Again, an interactive set of procedures for image filtering will be required. The interpretation will often result in drawing of boundaries between classes, and an efficient interface between the image processing system, which is raster-oriented, and a vector-oriented GIS is essential in this context.

As mentioned earlier, the non-specialist analyst will require assistance in order to select the most suitable sequence of procedures to solve a given problem. On-line help, good documentation and proper training will, of course, be of great value, yet development of decision support or expert systems might become relevant.

NOAA AVHRR-based monitoring of natural vegetation, crops and bush fires

The theory and methodology of monitoring herbaceous vegetation in the semi-arid tropics have been extensively described in the literature, particularly in the work of the GIMMS group documented in special issues of the *International Journal of Remote Sensing*;5/ no attempt to present it in any detail will be made here. The principle is simply that the photosynthetic activity is closely related to the normalized difference vegetation index (NDVI), calculated from NOAA AVHRR bands 1 and 2, and by monitoring NDVI through the growing season the biomass production may be obtained by integration. Atmospheric effects and effects of off-nadir viewing, which affect the individual NOAA AVHRR bands quite considerably because of the wide scan-angle, are suppressed by using NDVI rather than the original bands and by using maximum value composites (MVC). MVCs are created by assigning to each pixel the highest NDVI-value encountered in the NOAA images from a certain period, usually 10 days, and since all effects of haze, clouds etc. tend to decrease the NDVI, the highest value encountered is probably the most correct. Similar methods may be used to monitor crops, such as millet, in semi-arid areas, and to estimate yields.

The same NOAA AVHRR data are also well-suited for monitoring the extent of bush-fires by observing fire-scars. No generally applicable and fully automatic method seems to have emerged in this field, yet visual interpretation of NOAA-images appears to be quite efficient.

These applications of NOAA AVHRR data are, as mentioned earlier, among the candidates for operational applications in many dryland areas in the tropics. The parameters monitored are of great economic and environmental interest, the amounts of data involved are not exceedingly large, the cost of data is small, entire countries may be covered, and the required investments in equipment are limited.

The requirements concerning image processing methodologies and software may be summarized as follows:

1) The full 10-bit data should be handled by the system; discarding of the last 2 bits to make the data fit into a standard 8-bit data format will have strong negative effects on the quality of the results.

2) Proper software for utilization of the TBUS data, distributed with the NOAA AVHRR images, allowing radiometric calibration and more precise localization of the geographical position of each pixel, must be available.

3) Labour-saving production-line software for geometrical registration and co-registration of time-series of NOAA-images with sub-pixel accuracy is a presumption for operational use of the methodology. The high co-registration accuracy is particularly necessary in crop monitoring, since fields in semi-arid zones most often are small and

sometimes scattered, and degradation of the efficient spatial resolution of a multi-temporal NOAA data-set to several kilometres, due to imprecise co-registration, is therefore detrimental. Furthermore, MVCs tend to overestimate NDVI, if the co-registration is not sufficiently precise.

4) Routines for cloud masking, calculation of MVCs, for integration of NDVI and for spatial and temporal interpolation to "fill in holes" in NDVI time-series caused by cloud-cover are required.

5) Efficient and flexible routines for multispectral image display, required for visual identification of bush-fire scars, will be necessary.

6) Links to raster- and vector-oriented GISs, containing information of relevance for the interpretation of NDVI, e.g. maps of vegetation types and soil colour, are likewise necessary.

These demands are an example of application-specific requirements not usually met by standard general image processing software. Also the precise methods and software requirements will depend on the management context in which this monitoring activity takes place, and so all systems will have to be modified, requiring openness and modularity beyond what is often seen.

INSTITUTIONAL ARRANGEMENTS

Consequences of changes in the technological basis

Satellite remote sensing has from the outset been considered a high-technology activity, requiring complex and expensive equipment, highly skilled labour and high running costs. This has resulted in a centralized top-down organizational structure, both in many industrialized countries and in the developing countries. Many developing countries have not been able to utilize satellite remote sensing to its full potential and the organizational model may be one of the causes of this situation.

As outlined above, the technological development and the results of 20 years of training efforts may now have changed the fundamental preconditions to the extent that a more democratic (or anarchistic, if one prefers) bottom-up organizational model has become a realistic alternative: Small, decentralized, local-level organizations, be it within the public natural resources management sector, small companies, individual development projects of NGOs, will now be able to utilize certain satellite remote sensing methods efficiently. This opens new perspectives for the effect of remote sensing on natural resources management, since the technology will be on the desks of those directly involved in the management process. Therefore this change in organizational model should be supported, and it is a major challenge for the international remote sensing community and for those financing development activities

to find ways of promoting such local-level activities. Also it is important to discuss the future role of supra-national remote sensing centres, to ensure that the experience accumulated in these centres is utilized to support national and sub-national level organizations.

The example of the Centre de Suivi Écologique (CSE) in Senegal

CSE has roots back to the early eighties, when it was created by FAO and worked on monitoring of grasslands in northern Senegal in collaboration with the GIMMS group at NASA GSFC.6/ Later the financing was taken over by UNSO, and it has expanded its activities greatly to encompass a wide spectrum of environmental monitoring tasks, including a number of satellite-based observations such as:

1) NOAA-based monitoring of the development of the natural vegetation in the entire Senegal, using the above-mentioned NDVI-concept (operational). The data is combined with data from systematic air-based counting of livestock and information on water-provision from boreholes (in a GIS) to produce estimates of grazing pressure and fodder sufficiency.

2) NOAA-based estimation of crop yields, particularly millet and groundnuts (semi-operational/experimental).

3) NOAA-based monitoring of bush-fire scars (operational) and ongoing fires (experimental).

4) Meteosat-based assessment of rainfall, using the cold cloud duration methodology (Dugdale & Milford, 1986) (operational).7/

5) Estimation of agroclimatic parameters, such as actual evapotranspiration, from NOAA and Meteosat (experimental).

6) Use of high-resolution data for land-use/land-cover mapping (operational).

All these remote sensing and image processing activities are carried out locally, using PC-based image processing equipment, and equipment-costs constitutes only a small part of CSEs budget. CSE is in the process of establishing receiving facilities for NOAA-data, in order to support near-real-time applications, such as the monitoring of ongoing bush-fires.

CSE has a semi-independent status within the public sector in Senegal and is attempting to establish close links to local users of information, both within the national and local-level administration, parastatal organizations and development projects, in order to approach the ideal of being demand driven.

Since 1987 CSE has collaborated closely with the Institute of Geography, University of Copenhagen, (IGUC), which has developed all the image processing software used by CSE (the CHIPS system), assisted in establishment of facilities and carried out training of CSE-staff. By now CSE requires very little outside support in its daily activities, and the collaboration with IGUC is therefore aimed towards more long-term objectives, such as development of new methodologies and provision of new software-modules, supporting CSE's growing field of activities. Presently methodological developments in support of CSE include establishment of long time-series of directly comparable NOAA AVHRR NDVI data for assessment of long-term environmental trends in the Sahel, development of methodologies for estimation of the actual evapotranspiration, which is of great relevance for monitoring vegetation and crops in the drier parts of Senegal, where the NDVI-signal is small, and development of more sophisticated and interactive feature selection and multispectral classification methods.

CSE has had considerable success in proving satellite remote sensing useful in natural resources monitoring, and it may serve as a model for the establishment of similar activities in other places. Furthermore, the collaboration between IGUC and CSE, financed by the Danish Agency for International Development Assistance, DANIDA, exemplify how such "twinning-arrangements" with a long time-perspective may be to the benefit of both sides, and contribute to overcome thresholds in the process of operationalization of satellite remote sensing methodologies.

CONCLUSIONS AND CRITICAL ISSUES

Technological development has suggested that many satellite remote sensing methodologies have or will become within the reach of a large number of potential users involved in natural resources management. The main constraints on the efficient utilization of these methodologies in developing countries are probably related to questionable cost-efficiency (sometimes related to high prices of satellite data), lack of local demand for environmental information and inappropriate organizational structures on both national and international levels.

It is suggested that developers of methodologies and software should now realize that the use of remote sensing techniques will to an increasing extent take place on a decentralized level and become integrated in practical management activities. This again implies that demands on methodologies and software will change, since the composition of the user-community will shift from dominance of remote sensing scientists to thematic professionals, spending a minor fraction of their time on satellite image processing. Emphasis will have to be placed on improvement of facilities for integration of satellite-derived information and other data, on methods allowing efficient combination of visual and computer-based interpretation techniques and on improved user-interfaces and decision support systems, thereby making techniques more accessible to the natural resource management professionals.

FIGURE 1

Outline of a typical sequence of image processing and analysis steps involved in application of SPOT or Landsat data for land cover mapping. Identification of such features involves use of an intricate mixture of expertise within the field of remote sensing, knowledge about the optical properties of the object, insight into multivariate statistics and common sense. No simple or generally applicable methodology for feature identification can be pointed out, and trial-and-error plays a significant role in the process.

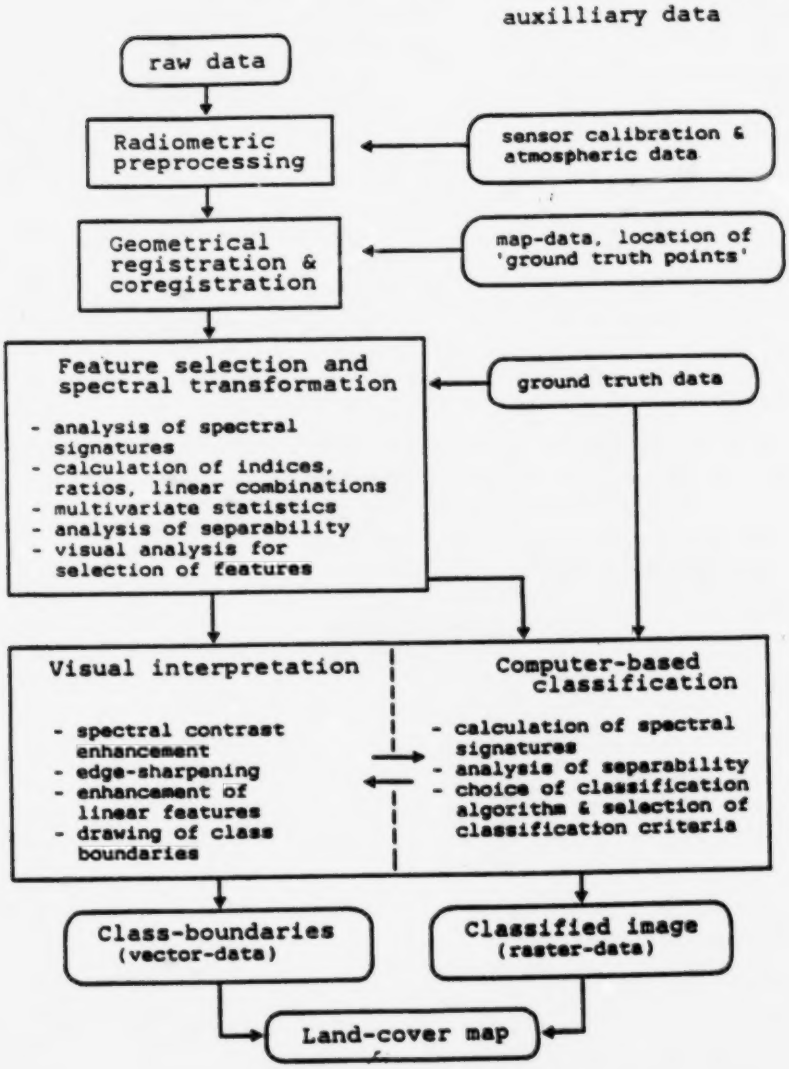
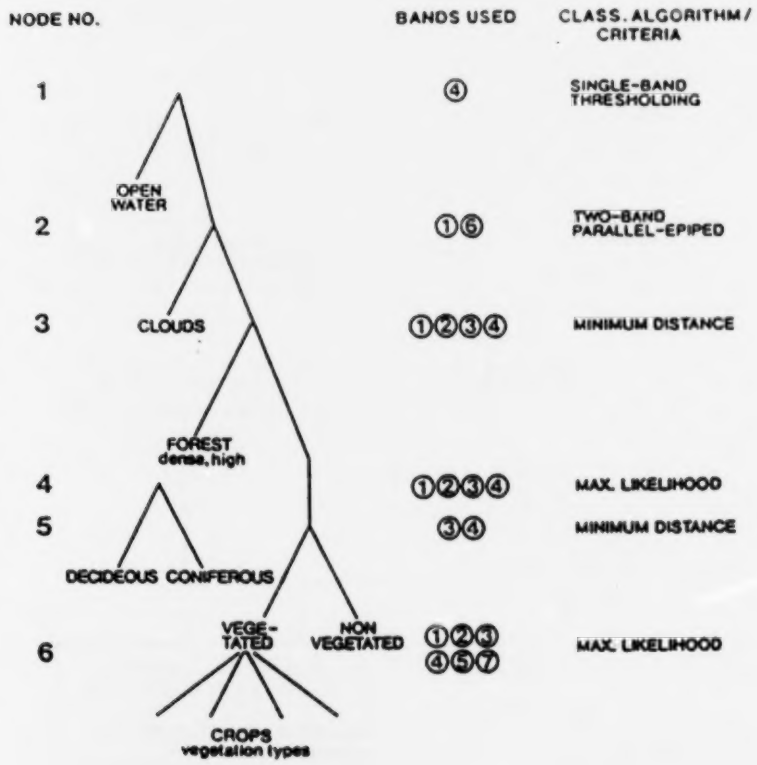

auxilliary data
raw data
Radiometric preprocessing
sensor calibration & atmospheric data
Geometrical registration & coregistration
map-data, location of 'ground truth points'
Feature selection and spectral transformation
- analysis of spectral signatures
- calculation of indices, ratios, linear combinations
- multivariate statistics
- analysis of separability
- visual analysis for selection of features
ground truth data
Visual interpretation
- spectral contrast enhancement
- edge-sharpening
- enhancement of linear features
- drawing of class boundaries
Computer-based classification
- calculation of spectral signatures
- analysis of separability
- choice of classification algorithm & selection of classification criteria
Class-boundaries (vector-data)
Classified image (raster-data)
Land-cover map

FIGURE 2

A sketch of a hierarchical classification procedure for land-cover mapping based on a Landsat TM image. Simple classification tasks, e.g. classification of open water, are first carried using simple and fast methods and few bands, and increasingly complex methods and more band are being used in later stages, where fewer pixels have to dealt with.



NOTES

1. Prince, S.D., Justice, C.O. and Los, S.O., Remote Sensing of the Sahelian Environment, CEC, DG8. JRC-Ispra/CTA-Wageningen, 1990.

2. ibid.

3. Falloux, F., "Land Information and Remote Sensing for Renewable Resource Management in Sub-Saharan Africa, a Demand Driven Approach," World Bank Technical Paper No, 108, The World Bank, Washington, D.C., 1989; Prince, et. al, op. cit., (1990).

4. Prince, et. al., op. cit., (1990).

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REMOTE SENSING'S PRESENT CAPABILITY FOR SUSTAINABLE AGRICULTURE DEVELOPMENT*

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INTRODUCTION

With the advent of satellite remote sensing technology, a wealth of information, both static and dynamic in nature, can be acquired with relative ease. There is an even bigger potential in resource management and environmental protection if updated information from satellite data can be integrated interactively with those from other sources in a GIS environment.

Four major characteristics of satellite remote sensing data that have revolutionized humanity's ability to observe the earth's features in a more expedient and effective manner are the following: (i) the data are collected in narrow electromagnetic bands ranging from visible through infrared to microwave, thus expanding the normal human visual perception beyond the visible light; (ii) they have a large area coverage that generates a synoptic view which makes them useful for contextual planning; (iii) they are collected at regular, repetitive intervals which is useful for monitoring purposes; and (iv) they are in a digital format, thus making computer processing possible.

Development in the field of satellite remote sensing is moving at a fast rate. This does not mean, however, that developing countries utilizing this technology can ignore proper planning. These countries stand to lose if concerted efforts are not made to develop indigenous capability to use the technology for national development. Among others, remote sensing has been proven helpful in formulating agro-development plans for sustainable food production in both developed and developing countries.

STATUS OF REMOTE SENSING APPLICATIONS FOR AGRICULTURAL DEVELOPMENT IN DEVELOPING COUNTRIES

Malaysia, like most developing countries, recognizes the need for an accurate land evaluation system for sustainable agricultural production. It is currently collaborating

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with Canada to create a computerized system to generate both regional and localized land evaluation models for sustainable agricultural production. This is the Land Analysis and Decision Support System (LANDS) and has in its shell a GIS component, a soil-crop suitability expert system, a climate analysis module, and a mathematical programming module. LANDS will be a revolutionary tool for agricultural land-use planning in Malaysia. Most resource data on topography, climate, land-use, soil and crop performance are made available via both ground surveys and remote sensing.

Agro-ecological mapping of Malaysia is being considered on a regular basis (every five years) to provide updated information for LANDS. For this purpose, resource data on soil, climate and crop performance are being updated via more detailed ground surveys whereas land-use data are updated using satellite remote sensing techniques (Landsat and SPOT). Crop performance data are also being monitored using NOAA-AVHRR data. Currently, only paddy crop yields are monitored for sustainable production in Malaysia under the aegis of the Agro-Climatic Impact Assessment (AGROCIA) programme, initiated by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), NOAA and USAID. The results have to-date been promising and it is envisaged that the technology will be extended to cover other crops by using NOAA, Landsat and SPOT data on a complementary basis.

Malaysia is also mapping soil-erosion risk areas using remote sensing and GIS technologies on a pilot basis. Such information is vital for agricultural development planners. They have to ensure that economic benefits derived from agricultural ventures should not be at the expense of soil erosion hazards which can lead to irreversible environmental problems. The assessment of the accuracy of results of such projects is being conducted with ground truth data and erosion simulation trials.

The experience of Malaysia in using remote sensing and GIS techniques for planning of agricultural development on a sustainable basis is still at its juvenile stage. This situation also seems to prevail in other developing countries. However, the level of involvement of these countries in the technology of satellite remote sensing varies considerably with the vast majority of them (including Malaysia) still developing their User Segment whereby expertise is being acquired in the use of this technology in various application sectors. A few countries (such as Thailand and Brazil) have moved a step further to embark on the Ground Segment with their own ground data receiving stations, fewer still (such as India and China), are already in the Space Segment with their own satellites and launching capability. International assistance is therefore needed for most of the developing countries to enhance their capabilities. This can be in the form of transfer of technical expertise from the developed countries to the developing countries, particularly in aspects related to the use of this technology in national development planning procedures including those for sustainable agricultural development.

Remote sensing technologies are being ushered into a new dimension with the advent of the active Synthetic Aperture Radar (SAR) satellite remote sensing systems such as Almaz of the Commonwealth of Independent States (CIS), ERS-1 of the European Space Agency (ESA) and JERS-1 of Japan. Data collected from such systems can contribute significantly to the efforts of tropical developing tropical countries which are agro-based to obtain cloud-free satellite data which is impossible from optical systems. Some developing countries are actively participating with the Russian Federation, ESA and NASDA (Japanese Space Agency) in the utilization of such data for varied resource and agricultural applications.

CONSTRAINTS

Most tropical countries face the problem of acquiring cloud-free data for operational use of satellite remote sensing technology for sustainable agricultural production. Although active sensor data are available to help alleviate this problem, most technology users in these countries have yet to acquire the expertise to process such data.

As mentioned earlier, many developing countries do not have ground reception capabilities for satellite remote sensing data. Data have to be secured from outside sources and therefore suffer from high cost and late delivery. After procurement the data, especially those on magnetic tapes, need to be specially archived and maintained, but such facilities and expertise are generally lacking. This may lead to the deterioration of the quality of information and eventually the loss of such information for future use. Consequently, there will not be reliable records on agro-history which are essential for future development planning of agricultural ventures.

Data with stereovision capabilities are still limited to the SPOT system. Additional systems are needed to generate a Digital Elevation Model (DEM) for topographical base mapping of the most inaccessible areas in developing countries, such as inland swamps and highlands.

PROPOSALS

The proposals put forth here are primarily aimed primarily at addressing the two major constraints faced by the remote sensing communities in most developing countries, namely data requirements and trained manpower requirements:

(i) Establishment of Satellite Data Centres

Satellite Data Centres with proper data archiving and maintenance facilities should be established among developing countries to furnish the supply of cost-effective and high quality data. These establishments should be based on a user

group network system at a regional level, where member countries can contribute resources to maintain the centre.

(ii) Participation of Developing Countries in New Satellite Programmes

Active participation of developing countries (as users of the technology) in new satellite programmes such as ERS-1 and JERS-1 programmes should be encouraged and supported by international agencies such as the United Nations. This will give the opportunity to scientists in these countries to acquire expertise in the newly emerging aspects of the technology, such as microwave remote sensing, from the developed countries.

(iii) International Programmes for Sustainable Agricultural Development

Agricultural development programmes such as AGRISTARS and AGROCIA should be extended to include developing countries. Such extension should be initiated on pilot scales to address the relevant issues and problems and to develop appropriate methodology suitable to prevailing conditions in these countries prior to embarking on an operational scale.

CONCLUSION

Satellite remote sensing offers a new capability for data gathering of the Earth's natural and agricultural resources. However, the use of this new technology is still predominantly confined to the developed countries. Two major problems faced by developing countries in their efforts to operationalize the use of remote sensing are related to data acquisition and the lack of skilled manpower to process and interpret the data. A concerted international programme is therefore required to assist the developing countries to use this technology for national development planning, particularly for agriculture development on a sustainable basis.

SATELLITE COMMUNICATION PROGRAMMES FOR RURAL EDUCATION AND DEVELOPMENT*

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INTRODUCTION

That satellite communications could revolutionize rural education leading to all-round development is a premise on which the planners in many developing countries have been working for several years now. The basic requirements and the attendant pitfalls have also been discussed quite extensively. Despite the difficulties there are success stories and several lessons to be learned from every experience. Not surprisingly, the Indian experience has been a mixed bag. Rural development is a complex issue, as it calls for inputs not only in communication but also in education, health care, agro-industrial technology, transportation, finance and most important of all, motivation. Moreover, in a country like India, the issue becomes much more complex because of the nature of the society -- a society of several languages, customs, races, religions, cultures and economic disparities. But the true impact of communications in general and satellite communications in particular could be understood when its relation to education and through education to the spheres of family welfare, health care, technology absorption, etc. are fully realized.

The Indian National Satellite System, INSAT, is a unique multi-purpose system not only in its technical configuration but also in its utilization. The three components of the INSAT system, namely the Meteorological Segment, Telecommunications Segment and the Broadcasting Segment, were incorporated primarily to serve the rural areas of the country. The distance insensitiveness of the satellite system provided an opportunity to instantly reach out to the remote and rural areas.

METEOROLOGICAL INFORMATION AND DISASTER WARNING

Even today, India is primarily an agricultural society with more than sixty per cent of its vast population living in rural areas. No doubt the dependence on monsoon

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rains has decreased in absolute terms with the developments in irrigation, transportation and agricultural practices that have taken place in the recent years. But farmers are still subjected to the vagaries of the monsoon. It is in this context that the meteorological segment on INSAT was given the highest priority in defining the INSAT System configuration. The Very High Resolution Radiometer operating in visible and infrared bands was added to the configuration to obtain cloud cover imageries, which forms the most important element of the weather forecasting system, particularly during the monsoon and pre-monsoon seasons.

The INSAT System provides for the dissemination of the weather information to all parts of the country, particularly to rural areas. There are two systems in operation. One is for dissemination of meteorological and agro-meteorological data to various weather offices, agro-meteorological centres and other interested users in a broadcast mode and is called the Meteorological Data Dissemination Service (MDDS). The other is a Disaster Warning System (DWS), which helps alert people in coastal areas of impending cyclones.

The MDDS combines the cloud cover imagery, weather fax and five channels of teleprinter data into one carrier, and this carrier is broadcast in the S-band. Simple receivers with 3 m mesh antennas receive this information. Thus all the weather information is available to the field offices very quickly so that they can make weather predictions for the local area. The multi-channel capability of this system can be used for various agro-meteorological purposes.

The INSAT Disaster Warning System is unique in many ways in bringing the benefits of satellite communications technology to the rural areas. India has a long sea coast and many coastal areas are prone to cyclones. The communications and power infrastructure are the first to be affected by the high winds associated with cyclones. The INSAT DWS helps to by-pass this communications network at the crucial time just before the cyclone crosses the coast. The system enables the Cyclone Warning Centre (CWC) to directly and selectively address a particular area likely to be hit by a cyclone. Simple receivers, which are an adoption of direct satellite-to-community TV receivers are located in coastal villages. These receivers are designed for continuous and unattended operation in rural coastal environments and are tuned to receive specific codes which are assigned to particular locations. After determining the likelihood of a cyclone hitting a place, the CWC selects the appropriate code and sends this signal to the satellite through an earth station. The satellite relays the signal back to the ground to be received by all the receivers. But only those receivers turned to the particular code transmitted activate a siren loud enough to be heard by people in the neighbourhood. The siren lasts for about a minute and then automatically switches off. The CWC comes on the air after this period with oral warning in the local language giving the details of the likely nature of the cyclone and the precautions to be observed. CWC can repeat this procedure as often as desired and can also change the warning messages as events develop. If the cyclone changes course, CWC can direct the warning to another area and

in fact gives out different warnings to different locations. The system has proved its efficacy in the successive cyclone seasons in the east coast of India. The initial deployment of 100 specially designed DWS receivers is now being expanded to cover more areas.

A Search and Rescue Transponder operating in the 406 MHZ band has been included in INSAT-2A and 2B spacecraft. This transponder will pick up any distress signal beacon operating in the 406 MHz band and provide an instantaneous alert. The system is designed to be compatible with the International COSPAS-SARSAT system. The main intention in including this payload on INSAT-2 is to encourage fishing vessels to carry 406 MHz emergency beacons so that in case of a distress they can send the alert messages which will be received by the Mission Control Centre and passed on to the Rescue Coordination Centres.

TELECOMMUNICATIONS

The role of communications in development has been extensively discussed in several studies over the past two decades. Strong correlation between telephone density and the development index has been demonstrated. It has also been established that for development to take place in any rural area, it has to have good telecommunications connections to the rest of the country and the world. The INSAT System provides this capability to access remote and rural areas. Special emphasis has been placed on engineering networks for the rural areas and the hill districts. Out of a total of 74 earth stations in the public telecommunications network, 53 are in remote areas. About 30 more stations are under construction in the Himalayan mountain regions. Road transportable and flyaway terminals have been introduced into the system to provide communications during emergencies and on special occasions.

Apart from a general improvement in the telecommunications infrastructure to which the satellite system has contributed substantially, a unique Satellite-Based Rural Telegraphy Network has been commissioned on an experimental basis. This is a VSAT-based network to improve the delivery time of telegrams in rural areas. The network consists of Rural Telegraph Terminals (RTTs) co-located with the Combined Post offices in villages or small towns and a hub station which also acts as a gateway to the national network. The RTTs centre around a 2.5 m antenna and battery operated electronics. The transmitter and receiver interface with a PC and VDU which acts as the input/output device for the telegram. The system operates in the TDM-TDMA mode with a transmission rate of 1.2 KBS in both direction. The signal architecture has been chosen so that the transmitter power requirements at the RTTS is minimized. Also the system capacity could be increased by addition of carriers in a modular fashion. Moreover, the RTT construction is also modular. The system has been found to be most suitable for the North-Eastern part of India, which has a hilly terrain which makes it difficult to install terrestrial systems.

A Remote Area Business and Messaging Network (RABMN) has also been commissioned. This network consists of VSATS of size 1.2 m to 1.8 m and a large hub station. Operating on a CDMA mode, this network provides the vital communications link to industries and businesses located in remote areas. The strengthening of the communications infrastructure in these areas attracts investment. As the RABMN which is part of the public network enables the user to own and operate the terminals, industry need not wait for the communications infrastructure to develop, but could order its own when it chooses. While RABMN is only a messaging network, a VSAT network operating at 64 KBS which could provide voice communications is on the anvil.

DEVELOPMENTAL AND EDUCATIONAL COMMUNICATIONS

Education and development go hand-in-hand. Satellite communications play a very significant role in distance education, which is probably the only way to educate the people in rural India quickly and inexpensively. In order to succeed, every one of the developmental programmes undertaken in rural areas, for family welfare, poverty alleviation, illiteracy eradication, improvements in agricultural practices or health and hygiene, must be backed by a massive education programme. The role that satellite communications can play in rural development was realized in India very early and several studies were conducted to identify and define the various aspects of developmental education using satellites. This was followed by the Satellite Instructional Television Experiment (SITE) in 1975-1976 using the NASA-loaned ATS-6 satellite. The satellite delivered instructional TV programmes to Direct Reception Sets placed in 2400 rural communities spread over six clusters in the most backward districts of India. This distance education was backed up by a vigorous programme of social research, feed-back mechanisms, a follow-up campaign and a technical maintenance scheme. Described as the largest experiment in mass communications, SITE paved the way to an operational, satellite-based distance education scheme by proving to decision-makers the efficacy of delivering developmental and educational messages via satellite.

Apart from direct-to-community TV transmissions, SITE also experimented with a Limited Rebroadcast System (LRB) wherein a 100 Watt VHF transmitter (upgraded to 1 KW) was used to provide local TV broadcasts. This transmitter, located in the PIJ village in the State of Gurat, led to the pioneering experiment in local TV broadcasting and developmental communications called the Kheda Communications Project.

The INSAT satellites carry two high power S-band transponders meant to provide direct-to-community TV transmissions. Though the initial plans called for a deployment of about 100,000 direct-to-community receivers all over the country, in the course of implementation it was decided to adopt the concept of using a large number of Low Power Transmitters (LPT) to cover towns with a population of approximately 100,000. This way the reach of television coverage was increased and today with over 530 transmitters, more than 80 per cent of the population and 60 per cent of the area has been covered with VHF transmissions.

However, there still remain two major issues in the use of satellite communications for rural development and education: i) the inexpensive access to the signal for the large under-privileged population, which cannot afford to own a TV set; and ii) the problem of operations and maintenance of community television sets which is really the answer to the access issue.

In India about 4,000 direct-to-community receivers as well as about 50,000 VHF community television sets have been installed. But the mushrooming of privately owned sets has placed the concept of community sets in the background. The problem of finding financial support as well as the difficulties inherent in maintaining community sets has only accentuated the situation. There are no simple answers and solutions.

On a different plane, the single television channel that the 532 transmitters networked through the satellite has to cater to the varied interests of urban and rural populations. Current affairs, entertainment, education, departmental programmes all have to share this channel and the available time. In addition, the local, regional and national level programmes have to compete for time on this one channel and in many cases the language could be different in each case. Thus a complex balancing act must be performed, and it is no wonder that the situation is not fully satisfactory.

Problems notwithstanding, several hours of developmental programmes are currently being broadcast. The impact of these programmes has not yet been fully researched and understood, though the social impact should no doubt be enormous considering the vast reach of the medium. Three structured telecasts have also been organized. These are:

i) The country-wide classroom conducted by the University Grants Commission for two hours everyday. The programmes are meant for university and college students and are meant to supplement classroom lectures and hence do not follow a strict syllabus.

ii) Educational television programmes for school children broadcast in the local language in the SITE states on a regular basis. These are really meant for rural schools where TV brings the teaching aids which are otherwise unavailable or scarce, to the classrooms.

iii) Broadcasts by the Indira Gandhi National Open University. They are curricula-based lectures for the students of the Open University and are delivered in English.

RADIO NETWORKING

Notwithstanding the dramatic expansion of the TV network, radio has a much deeper penetration in the rural areas. Moreover, the access is also better because a radio set costs a fraction of what a TV set costs. The high mobility of the radio sets enables people to carry them to their workplace, be it in the agricultural field, on a tractor or to the market place on a bicycle. Radio does not demand an undivided attention either. All this makes radio an ideal medium for developmental communications. In India the spread of local radio is far-reaching and programmes are broadcast in almost all local languages. The intense competition for air time witnessed for TV is not present. Even for networking purposes several radio networking channels using INSAT are available. The present complement of seven channels is being expanded to 28 and both national and regional networking is extensively done.

INTERACTIVE TRAINING NETWORKS

Realizing the shortcomings of the present situation, the Indian Space Research Organisation (ISRO) has embarked upon a scheme of further experimentation and demonstrations in distance education using satellites for development. These experiments take into account new technological developments in the field as well as the new and changed requirements that have arisen with the passage of time.

Training of primary school teachers, village level workers or extension workers, adult literacy activists or volunteers and retraining of industrial workers are three areas which were selected for further experiments. It was clear that while reaching the public at large is ideal, the satellite system is much more effective in training the trainers. The reasons are not difficult to discern. The motivation level of trainers is generally high, the technical problems of set maintenance are easily solved as there is an organization behind the endeavour, attendance during the training sessions are high and follow-up actions are automatic.

Since such training of trainers must be interactive, a two-way audio and one-way video system was developed. The trainers or village level workers already have a wealth of information that they could share with each other and it is necessary that the medium enables this. Hence the interaction is not only between the lecturer and students, but also among the students. The basic system consists of a teaching end, a model classroom with the teaching aids such as blackboard, video recorders and personal computer terminal. This classroom is located close to a satellite earth station which is again configured to be as simple and inexpensive as possible. The distant classrooms are spread over a vast area, the area depending on the nature of the course. The classrooms consist of a small terminal, typically a 3 m wire-mesh antenna for receiving the TB programme. The audio talk-back is provided either by a normal dial-up telephone link to the teaching end or an audio uplink terminal. The uplink terminals are located at places which are not well connected with telephone links. The uplink

terminals operate with small antennas that may be the same as the receive antenna, and one to ten-watt power amplifiers. At the end of a lecture or a demonstration video, the persons assembled at the distant classrooms could ask questions to the resource person at the teaching end and obtain clarifications.

The system is designed to operate in the C-band. Even in a large system it is necessary to have only a few interactive terminals. When the dial-up telephone links are added, the proportion of classrooms that can ask questions becomes fairly representative of any typical classroom. As the entire system could listen to the questions and the answers, the participation becomes complete. Since C-band receive only terminals have become quite popular in India and are available at reasonable prices over the counter, the use of C-band facilities for the implementation of the interactive distance education system based on the satellite medium has become prevalent. A specially engineered demand assignment equipment to enable the distant classrooms to register their intention to ask questions and be assigned its turn in the queue is also being developed and tested.

So far three experiments have been conducted to demonstrate the system's viability. These are:

i) An experiment to train adult education activists. This experiment was conducted in the Gujarat State in cooperation with the Gujarat Vidyapeeth, which is the focal point for adult literacy in Gujarat. This is a state level experiment.

ii) An experiment in retraining industrial workers. This was conducted on a national scale in which the distant classrooms were located at the factory premises. The training was concentrated on a specific trade of common interest to all participating industrial units.

iii) An experiment in informing agricultural extension workers about the findings of remote sensing data in one district in Haryana State. This district level experiment concentrated on the problems of one district and hence provided an opportunity for intensive interaction between experts from the Agricultural University, extension workers and the farmers.

The flexibility and adaptability of the system having been thus proved, the next step will be to operationalize such schemes on a pilot scale in selected districts and selected industries. The increase in space-segment capacity provided by the recent launch and commissioning of INSAT-2A spacecraft will provide an opportunity to do this.

TABLE-1

INSAT DISASTER WARNING SYSTEM (DWS)

Uplink EIRP	:	62.6 dBW
Uplink Frequency	:	5859.225 MHz
Satellite EIRP	:	20.2 dBW Min.
Downlink Frequency	:	2559.225 MHz
Receive Antenna	:	3.66 MO
G/T	:	8.2 dB/°
Receive Bandwidth	:	170 Khz
Voice	:	3.4 KHz
Data	:	1.2 KBPS with 1023 bit Pseudo-Random Code
Modulation	:	FM

TABLE-2

INSAT METEOROLOGICAL DATA DISSEMINATION (MDD) SERVICE

Uplink EIRP	:	62 dBW
Uplink Frequency	:	6 GHz Band
Satellite EIRP	:	20.2 dBW
Downlink Frequency	:	2.5 GHz Band
Receive Antenna	:	3.66 MOMesh Reflector
G/T	:	8.2 dB/°K
Receive BW	:	170 KHz
Data	:	Processed Cloud Imagery (2.4 KHz) FAX Charts (2.4 Kbps) Met. Data (2.4 Kbps) All FDM multiplexed to generate a composite baseband signal of 10 KHz bandwidth
Modulation	:	FM

TABLE-3

SATELLITE BASED RURAL TELEGRAPHY NETWORK

NETWORK FEATURES

Configuration	:	STAR
Access Scheme	:	TDM (HUB STATION TO RTT)
	:	TDMA (RTT TO HUB STATION)
Bit Rate	:	1.2 KBPS
Modulation	:	BPSK
BER	:	$1x10^5$
Frequency Bands of Operation	:	6/4 GHz Band
Satellite EIRP	:	2 DBW

REMOTE TELEGRAPHY TERMINAL (RTT) FEATURES

Antenna	:	3.66m Mesh/2.5m GFRP Solid Dish
G/T	:	15.7 dB/°K
RF Power Amplifier	:	1 Watt
Power Consumption	:	75 Watts at 48 V/D.C.

HUB-STATION FEATURES

Antenna	:	11 MO
G/T	:	31.7 dB/°K

INTEGRATION OF REMOTE SENSING AND GIS IN LAND USE MAPPING*

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INTRODUCTION

For many years remote sensing techniques and methods have been developed in Poland independently from geographical information systems (GIS). In the process of extending GIS applications it was necessary to take into account such a valuable and constantly changing source of information as remote sensing. As a result of manual photointerpretation, we obtain manuscripts of thematic maps which contain information similar to that commonly used in GIS data sources.

Using digital image processing systems we get digital data representing spatial distribution of the phenomena being interpreted. Most existing GIS packages can easily adapt such data sets. The potential of combining RS with GIS is evident and leads to more integrated solutions.

In the late 1980's the Institute of Geodesy and Cartography initiated work on a GIS for environmental applications, called SINUS (abbreviation from the Polish for Environmental Information System). At the same time, the Institute was involved in a United Nations Food and Agriculture Organization (FAO) project that required a new land use map of the country. The Landsat TM colour composites were the primary source materials used for development of the map. It proved to be a good opportunity to use digital techniques for further processing of interpreted satellite data.

These two projects influenced each other because the process of land use mapping was valuable training field for development of the SINUS GIS. Many of the function requirements for SINUS were stimulated by the processing requirements that emerged from development of the digital land use maps.

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FUNCTIONS OF THE SINUS SYSTEM

In the period 1988-1991 the SINUS GIS was developed to facilitate spatial data acquisition, analysis and presentation. One of the primary reasons for undertaking such an effort was the lack of GIS packages on the Polish market. The technological embargo which then existed was also a motivating force behind the development of the system.

It was developed for use with PCs, which is the most popular computer equipment in Poland. The system supports many digitizing devices as well as plotters. It uses both vector and raster data models. Most of its operations are analogical to other GIS packages and the respective modules contain the following functions:

Data acquisition

- Interactive digitizing
- Scanning and vectorizing

Database creation

- Data editing (vector)
- Topology construction
- Data verification
- Polygon encoding

Data transformations

- Projection calculations
- Sheet processing
- Coordinate transformations

Spatial analyses

- Overlaying
- Feature classification
- Extraction/selecting
- Voronoi polygon creation

Data conversions

- Raster/vector conversion
- SINUS/other package conversions (ARC/INFO, SPANS, etc.)

Cartography display

- Cartographic signature designing
- Map layout editing
- Output on printers
- Output on plotters

The above-mentioned functions were used for establishing seven layers of a national environmental database, namely:

- Administrative division
- Soils
- Geomorphological forms
- Main reservoirs of underground water
- Forest administration division
- Hunting units
- Land use

LAND USE MAPPING IN POLAND

In Poland several land use maps were developed. For example, a land use map of Poland at the scale 1:500,000 from the 1950s was edited by Uhorczak on the basis of topographic maps at the scale 1:100,000. A land use map at the same scale was published in 1982 by the Institute of Geodesy and Cartography. The source materials for that edition were comprised of photos from MSS images as well as from aerial photos. There are also many large scale land use maps covering some parts of the country. However, they were generally the result of project-oriented initiatives rather than systematic mapping activity.

In 1989, the Institute of Geodesy and Cartography began a new project for elaboration land use map of Poland at the scale 1:250,000. The mapping process was digitally driven by means of the previously described system. The flow diagram below presents the main stages of the project.

PHOTOINTERPRETATION

The Landsat-5 Thematic Mapper provides images at the resolution 30 m. The most valuable but also expensive are digital data it produces. The alternative product is colour composite obtained on film by combining defined spectral intervals of some spectral bands. Such an image is much cheaper and enhances just the phenomena that are subject of further interpretation.

Poland is covered by 26 scenes of TM and is mostly clouded in some parts of its territory on the specific day. So it is rather impossible to collect all necessary images for

the country from one season. In the case of the project the scenes were gathered from two years (1987,1988).

The elaboration of the land use map's legend was the first task after purchasing colour composites. Based on the analysis of received satellite materials there were distinguished the following 25 classes of land use/land cover:

- Waters
- Waste land
- Transportation

Agriculture

- Cultivated lands : arable land up to 80%
- Arable land with small grasslands
- Arable land and small forested area
- Arable land with small grasslands and forested area
- Fruit-farming and arable land
- Orchards and gardening lands

Grasslands

- Occasionally flooded grasslands
- High situated grasslands
- Peaty grasslands
- Anthropogenic grasslands
- Grasslands and small forested areas

Built-up areas

- Complex urban area
- Urban and suburban scattered built-up area
- Blocks of flats with parks

Industrial terrain

- Mining excavation and topsoil destroyed area
- Industrial plants and terrain

Forests

- Coniferous forest stands (above 80 per cent)
- Deciduous forest stands (above 80 per cent)
- Mixed forest stands
- Deteriorated forest stands
- Trees and bushes planted

After a short period of training, a group of photointerpreters began elaboration of manuscripts of the land use map. The manuscripts were made on transparent foil. Each sheet had been covering one satellite scene and was complemented by the set of

control points located at the geographical grid nodes. Elaboration of the manuscripts concluded the remote sensing stage of the project.

DIGITIZING OF MANUSCRIPTS

The manuscripts of the land use map were elaborated at the same scale and projection as colour composites, i.e. scale - 1: 250,000 and projection - Space Oblique Mercator (SOM). The digitizing programme has been equipped with the projection conversion procedure to enable transformatting coordinates to the SOM's Cartesian coordinate system. The procedure was based on the formulae derived by J. Snyder.1/ One of the most important benefits of using SOM coordinates was the possibility of plotting the results of digitizing and to compare them with the source materials. The process of digitizing the manuscripts took about one year. All errors found during the detailed checking of verification plots were the subject of further editing.

EDITING AND ENCODING

After the creation of a vector-oriented database, a set of operations was conducted in order to find all inconsistencies disabling the construction of coherent topological relations. The process of vector database editing was performed by a dedicated, manu-driven programme. It took another nine months to clean up the database and to create consistent polygon topology.

The next step, polygon encoding, was accomplished by placing labels with attached codes inside each polygon. Most of the labels could be set while digitizing and/or editing was taking place. One of the programmes has been creating links between labels and polygons. The SINUS system also provides the additional possibility of interactive encoding. Using the appropriate programme, a user can locate a label inside a polygon by pointing at it with the cursor and the process of linking the label/polygon can be immediately observed. As a result of the operation the pointed polygon's filling is adequately adjusted to the entered code.

SHEET PROCESSING

A satellite scene was a spatial framework for the processes described above. This means that an independent database unit was covering one TM scene. Scenes were blocked within separate orbits for which the independent individual coordinate system was established. In order to create a uniform coordinate system each piece (scene) of the database has been converted to geographical coordinates.

Because the number of polygons exceeded the system's capacity, it was not possible to directly join adjacent pieces to create unified coverage for the country. The

next step after transforming the coordinate system involved the partitioning of each scene along the geographical grid. Small fragments were then assembled into map sheets. The complexity of land use units enabled the creation of sheets with the extent of 1.5 longitude by 1 latitude. About 40 such sheets covered the entire country.

The process of assembling the scenes resulted in inconsistency on the edges of the scenes. The errors arose mainly during the photointerpretation process. They originated from misinterpretation of similar land use classes but were also the result of the naturally limited accuracy of digitizing. As a consequence of this and the additional processes of vector-oriented database editing, encoding and topology rearranging has been initiated.

CARTOGRAPHIC OUTPUT

The SINUS system provides a set of cartographic displays of the content of its databases. The simplest one can be printed on a variety of printers (from matrix to laser). This form of presentation has been useful during the verification process when the contents of the database must be graphically expressed. The completeness of coding can be checked using such printouts.

Pen plotter drawings can be used for singular presentations of land use maps whereas a precise flatbed plotter is applied when final drawings are required for further printing processes.

The last form of cartographic presentation is provided by graphic display output. This instant image can also be saved in more durable form like digital files. These can in turn be inserted into one of the graphic software programmes and merged with other drawings so they can be published in more complex editions.

The contents of the vector-oriented database were used in the process of publishing a forest map at the scale 1 : 500,000. In order to extract just the required contents of the database, a special programme for extracting some features was used. The programme automatically creates a new set of database files which are then topologically integrated and ready to be used. For the purpose of the map all forest classes were merged, whereas built-up areas and waters formed background contents data sets.

Some additional information from other source maps was acquired by means of scanning and vectorization. All digital coverages were transformed to Albers Conical Projection. The assembling of data from various sources produced many problems of fitting each other. In the case of the map being described, the spatial location of different data appeared quite precise.

CONCLUSIONS

The production of the first digital land use map in Poland resulted in many practical and methodological experiences. The side effect of the project was the refinement of the in-house developed SINUS GIS to meet the new requirements which emerged from the exercise. A set of remarks were prepared for photo-interpreters regarding the preparation of manuscripts. Additional capabilities of the SINUS system such as scanning and vectorizing forces strict discipline among the photo-interpreters.

The remarks seem to be useful earlier than we expected. The European Community's CORINE programme was conducted with a lot of interesting and valuable data sets. One of them is the CORINE Land Cover data set elaborated by some European countries, including Spain, Portugal and Luxembourg. It has been suggested that the existing data sets and those currently under elaboration be extended to the rest of the continent. It is very likely that the Institute of Geodesy and Cartography will this year commence the project of land cover for Poland.

The scale of the new edition of digital land cover map will be more detailed than those described above, i.e. 1 : 100,000 and for some regions of special environmental concern, sheets at 1 : 50,000 scale will be elaborated. The project will utilize CORINE Land Cover methodology and nomenclature. However, the technical means will be selected without restraint. In the case of the Polish project we are going to intensively use the SINUS system for data acquisition, verification, cleaning and possibly for cartographical presentation, though the last process is not a subject of the contract. The final product should be in digital form and in ARC/INFO format. The SINUS system is equipped with a set of data conversion functions (to and from ARC/INFO as well) so the transmission of final SINUS databases to ARC/INFO coverages will be a routine process.

NOTE

1. Snyder, J., Map Projections - A Working Manual, U.S. Geological Survey Professional Paper No. 1935, Washington, D.C., 1987.

FIGURE 1 - FUNCTIONING OF SINUS

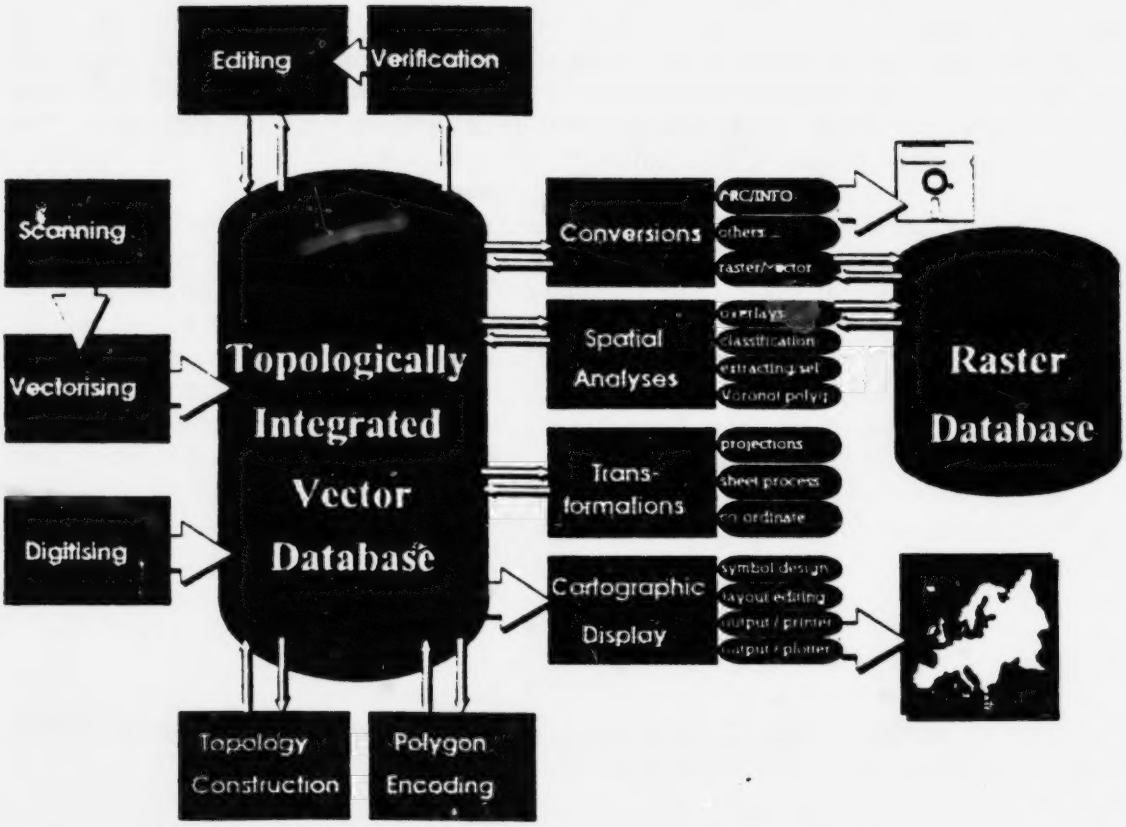
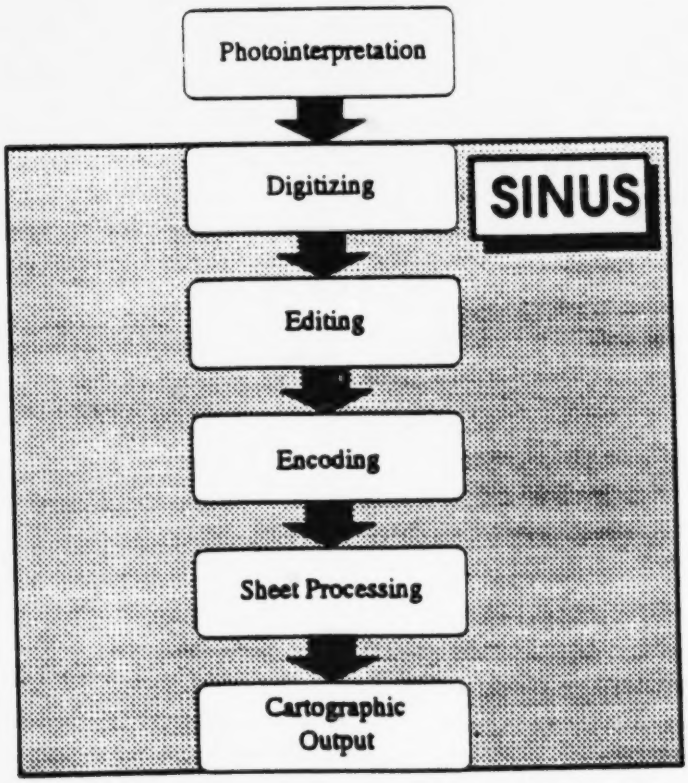


FIGURE 2 - INTEGRATION OF REMOTE SENSING AND GIS IN LAND USE MAPPING



A PRACTICAL APPROACH TO REMOTE SENSING APPLIED IN TERRAIN INVENTORIES*

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INTRODUCTION

APPLIED REMOTE SENSING - GENERAL ASPECTS

Terrain Inventories and Remote Sensing

An assessment of the physical properties of the environment and its response to management is required in agriculture and forestry for informed decision making in rural and urban planning, for feasibility and design studies in land development projects, and for many engineering works. The practical purpose of such surveys is to enable more numerous, more accurate and more useful predictions to be made for specific purposes than could have otherwise been made and also to survey and monitor the effects of various projects.

To achieve this purpose, it is necessary to determine the distribution and pattern of various terrain features and to divide this pattern into relatively homogenous units, to map the distributions of these units, thus enabling the properties over any area to be predicted, and to characterize the mapped units in such a way that useful statements can be made about their land use and potential land response to changes in management.

It is sometimes said that the purpose of a terrain inventory is to make a land use map, a slope map or a vegetation map etc. As a statement of purpose, this is inadequate. What is misleading is the implication that the map is a desirable end in itself. Passive acceptance of this notion can lead to an imbalance of effort, with unnecessary time and expense being devoted to mapping of terrain element distributions and routine analyses to characterize the mapped units, with insufficient effort devoted to finding out what the map is likely to be used for and what terrain properties have a bearing on possible courses of action.

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* This paper, which was presented at the Second United Nations International Training Course in Remote Sensing Education for Educators, organized in cooperation with the Government of Sweden, held at Stockholm and Kiruna, Sweden, 11 May to 12 June 1992, does not necessarily reflect the view of the United Nations.

A terrain survey is not an end in itself. Its utility should not be simply equated with the accuracy with which it predicts environmental conditions, without regard to whether these properties are significant in practical land management. Survey of physical terrain properties is usually a means of helping farmers, foresters, engineers, planners, development agencies and other users to make wise decisions about land use and management. Accordingly, in the initial stage of such a survey, much attention needs to be given to who the potential users of the survey are likely to be and what kinds of information they are likely to require. Consequently, anyone commissioning an inventory and assessment survey should give careful thought to what he needs to know, and should communicate this clearly to the survey team.

The Three-Level Approach

The traditional way of collecting information about the ground, water, plants, etc. of a region has been to travel in the area, make field observations and indicate features of interest on more or less primitive maps. After a certain number of traverses, a general idea of the qualities of the area could be presented. A denser network of observations resulted in better understanding of even detailed features, which could facilitate location and exploitation of natural resources of the area.

With a more general use of aerial photographs the initial field observations could be reduced drastically. The experienced photo interpreter may in a short time identify and delineate features that required weeks or months to discover during exploratory travels.

Photostudies usually require some inspection in the field in order to check the quality of the work and correct mistakes made during the photo analysis. This way of making a terrain inventory can be called a two-level approach, where analyses of the aerial photographs allow an early concentration of the field work to areas of specific interest or can serve as input to monitoring programmes.

A new step in the development of terrain inventory and monitoring techniques has been taken with the introduction of the Landsat and SPOT satellites. The work can now follow a three-level approach.

The first stage in such a three-level regional terrain analysis is to study the satellite images, delimiting areas or sites of specific interest or potential. In order to get a more detailed view of the areas selected aerial photographs are studied in a second stage. The photo analysis will indicate a number of limited areas, some or all of which must be visited in the field, depending on the type of information required.

SATELLITE REMOTE SENSING

Landsat and SPOT

A considerable time has now elapsed since the first civilian Earth Resources Technology Satellite was launched in 1972. Since then data and images from all five Landsat satellites have supplied us with an immense amount of information for immediate use or as invaluable reference data for the future.

From the beginning, the Landsat programme has been experimental and no commitments were made concerning future technical or operational conditions nor concerning the lifetime of the project. As Landsat 5 has served faithfully since early 1984 it can soon be expected to cease functioning and the first Landsat era will come to an end.

A second Landsat programme, now fully commercial, is planned to start in 1991-1992. It will be based on more sophisticated technology and with improved technical and operational performances. However, until the new programme starts a gap in Landsat quality data retrieval may be expected.

To a large extent this gap is bridged by the SPOT-system, which started in 1986 and is able to submit high resolution data and images, at least until the turn of the century. In several respects SPOT is similar to the Landsat system, in others the SPOT offers new and more valuable options, such as higher resolution and stereoscopic coverage.

Thus, the future seems rather promising for applied remote sensing during the next decade, judging from the availability of platforms and sensor systems as well as concerning the distribution of data.

In order to be able to analyze and evaluate satellite images or data a basic understanding of the technical background of remote sensing is essential.

TECHNICAL BACKGROUND

The Electromagnetic Spectrum

We can think of electromagnetic radiation as energy transport in the form of a wave train, where the distance between the wave crests, i.e. the wave length, can differ.

Figure 1.1a shows a section of the electromagnetic spectrum and introduces some of the terminology.

To the left in the spectrum in Figure 1.1 we find the shorter wavelengths, the ultraviolet or UV radiation. This type of radiation is of minor interest for remote sensing purposes. More important is the tiny part of the spectrum we call visible light. From 0.4-0.7 m (micrometre = 1/1000 of a mm) our eyes work as sensors and, within this range, we experience the radiation's different colours determined by wave-length (Figure 1.1b).

To the right we enter the wide infrared part of the spectrum. This range is usually divided into two subareas, reflected infrared (or near IR) 0.7-1.5 m, and thermal infrared from 1.5-1,000 m (the latter is often divided into middle and far-infrared). The crucial difference between the two is the energy source which, in the reflected IR-range - is the sun, while in longer wavelength - the thermal infrared, is the Earth itself, emitting heat from its surface. Beyond 1 mm wavelengths we call the radiation microwave and above 0.8 m we enter the radio area.

Spectral Reflectance

When light from the sun hits an object on the ground, some radiation will be absorbed, and some will be reflected or, more correctly, re-emitted.

This spectral reflectance varies with the object, and helps us to distinguish the various details around us, through colour, brightness, etc.

It is possible to measure the intensity of the light leaving an object and compare this value with the intensity of the light coming from the sun. If this is one for a small portion of the spectrum at a time, it is possible to construct a spectral reflectance curve (Figure 1.2).

The proportion of incoming sunlight that is re-emitted by some terrain objects within the visible and near infrared range of the spectrum is plotted in Figure 1.2.

We can immediately notice that different objects have different spectral characteristics and that the spectral reflectance of the same object may have large wavelength variations.

Clear water, for instance, will absorb the major part of the sunlight and re-emit more radiation as the sediment particles will contribute to a higher reflectance. The major change will occur in the red and IR parts of the spectrum.

Turbid water loaded with sediment will re-emit more radiation as the sediment particles will contribute to a higher reflectance. The major change will occur in the red and IR parts of the spectrum.

Dry soil sends back more radiation than wet soil, and will come out brighter in a satellite image. As soon as it gets moist or wet, the water in the soil will absorb the light, less will be re-emitted, giving the soil a darker tone.

There are also soils which are dark in themselves, such as vertisols and soils with a higher content of organic matter. These will appear dark, regardless of being dry or wet. The spectral reflectance curve in the diagram will be lower than the soil curves shown in Figure 1.2.

One interesting and important curve is the reflectance of healthy green vegetation. Typical is the high absorption by the plants in the visible part of the spectrum. The plant takes care of most of the incoming energy for its growth and the production of new tissue during photosynthesis. The small peak at 0.5-0.6 m is the reason why we experience vegetation as green.

Starting at the lower boundary of the near IR range of the spectrum, there is a sharp rise in the reflectance curve, often called the chlorophyll effect. The pigment of the levels, the chlorophyll, is very efficient in absorbing visual light but not as efficient in the infrared part. Most radiation penetrating into the superficial cells of the leaves will be reflected in the walls of the cells and will leave the plant.

The intensity of the chlorophyll effect is a function of the type and status of the plant, water content of the leaves, etc. Because of the chlorophyll effect, pixels covering wilting or dying plants will be low light intensity values in the infrared sensors, while living, healthy ones will show high values. This feature can be an advantage when making plant inventories, telling if plants are under water stress or suffering from diseases, studying land use patterns, etc.

Knowledge about the spectral reflectance of various terrain features can help optimize the conditions for selecting satellite registrations for various practical applications.

REMOTE SENSING SATELLITES

The Landsat System

Data and images from the Landsat system have been available since 1972, which means that most areas of the world are now well covered with several registrations taken at different seasons. This repeated, or multitemporal, coverage is one of the important advantages of the system as it will permit early detection and monitoring of environmental hazards and changes, season-dependent changes in farming, natural vegetation, etc.

Another advantage of greater importance, compared to conventional aerial photography, is the multispectral recording technique used. Instead of taking one single image of the scene, as with camera and film, the Landsat multispectral system records four images from separate sections of the visual and infrared spectrum. Studying an image from a specific part of the spectrum or combinations from two or more bands, can help us to differentiate between terrain features and details, which otherwise are difficult to separate.

Figure 1.3 gives a generalized idea of how the multispectral scanning (MSS) of the Landsat system works. The oscillating mirror scans the ground along lines, receiving light from areas roughly 80x80 m on the ground. The light is directed in sensors recording the intensity of the radiation for four different wave-length bands. These registered spectral bands correspond to what our eyes see as green and red colours and to near infrared radiation, which is "invisible" to our eyes. Precise waveband intervals for the two Landsat sensor systems, MSS and Thematic Mapper or TM which is presented later in this section, are found in Table 1.1.

Each scanning line contains several thousand 80x80 m areas called picture elements or pixels. Each pixel can be located geographically and shows the light intensity for each of the four separate spectral bands. From the pixel-mass recorded any part of the complete registration (185x185 km^2) can be presented as an image to a desired scale in black and white or in colours that enhance the terrain objects of special interest most effectively.

Various kinds of standard products as well as tailored, on-request processed images can be ordered from a number of distribution centres all over the world.

The recorded information can also be ordered as tapes or diskettes for computer based analyses. For instance registrations from two or more occasions can be compared, pixel by pixel, allowing multitemporal studies such as change detection, monitoring of trends and detection of time-related features for the whole Landsat scene or parts of it.

The registered data can also be used for automatic terrain classification. This way of using the satellite data is based on a number of limited test areas with known characteristics of groundwater, vegetation, land use, etc. A computer analyzes the satellite registration for these test areas, after which it may be possible to indicate all terrain in the area with the same spectral properties.

Since 1982 Landsat 4 and 5 have carried an additional sensor system besides the MSS, the highly sophisticated Thematic Mapper or TM-system. It records 256 intensity levels (compared to 64 with the MSS) in six wavebands with a spatial resolution of approximately 30x30 m and on the thermal recording channel with 120 m pixel size. The area covered by TM is approximately the same as for MSS, 185x185 km^2.

TABLE 1.1 - WAVEBANDS FOR LANDSAT AND SPOT DETECTORS

Band No.	Landsat MSS m(micron)	Landsat TM m	Landsat XS m	SPOT P m
1	0.5-0.6	0.45-0.5.2	0.50-0.59	0.51-0.73
2	0.6-0.7	0.52-0.60	0.62-0.68	
3	0.7-0.8	0.63-0.69	0.79-0.89	
4	0.8-1.0	0.76-0.90		
5		1.55-1.75		
6		10.4-12.5		
7		2.08-2.35		

The SPOT System

The SPOT satellite is in many respects similar to that of Landsat. It has similar multispectral and multitemporal options as well as a potential of large area coverage in a single scene . However, in Table 1.2 some important differences between the two systems can be observed.

TABLE 1.2 - TECHNICAL DATA FOR THE LANDSAT AND SPOT SYSTEMS

	Satellite Images		
Features	LANDSAT MSS	LANDSAT TM	SPOT
Available since	1972	1982	1986
Type of registration	MSS	MSS	Pan and MSS
Frequency	Multitemp	Multitemp	Multitemp
Area coverage, (km^2/image)	34000	9000	3600
Pixel size	50-80	30	10, 20
Stereoscoping viewing	No	No	Yes
Tailored Products	Yes	Yes	Yes
Image costs (USD/km^2)	0.02	0.1	0.5

(MSS=multispectral scanning; TM=thematic mapper; Pan=corresponds to B&W photography recorded as digital data)

The highly increased resolution of the SPOT satellite is maybe the most important feature of the system. Terrain features of a size of approximately 10 m can be observed in the black and white registrations, and approximately 20 m for colour.

A most interesting option is also the stereoscopic coverage possible with SPOT registrations, while Landsat only gives a flat representation of the land surface. With SPOT there is a possibility for topographic mapping, slope measurements, etc. Recent studies indicate that it is possible to produce topographic ortho-photo maps to the scale of 150,000 and smaller, with a contour interval of 20 m, through direct measurements in the digital image data.

With the high resolution of the SPOT system follows a drastic increase in the numbers of picture elements to be handled per area unit. To be able to take care of all these data, the size of the scene has been reduced to approximately one tenth of that of the Landsat MSS scene, or 3600 km^2. More SPOT images will be required to cover the same area as with Landsat and the cost will be higher.

Cost relations for images produced from the three satellite systems are indicated in Table 1.2.

The access to images and data improved with the SPOT system. Data from the satellite are received at a number of stations around the globe. The northernmost one, at Kiruna in northern Sweden, has direct contact with the satellite during most orbits and can "tap" its data frequently. Images or computer tapes from already existing registrations can usually be delivered within 3-4 weeks. It is also possible to order new registrations over areas of specific interest.

IMAGE PRODUCTS FOR VISUAL ANALYSES

Colour Composites from Digital Data

When light passes the lens of the eye it will fall upon sensors in the retina and we will experience the shade of colour of the object we are observing. There are three types of sensors, each one sensitive to one of the additive colours - blue, green and red.

If these three colours are mixed in different proportions it is possible to create any shade of colour. Together in equal proportions they form white light. A colour TV works along the same line, superimposing three images upon each other, one in blue, one in green and one in red.

So is also the case with a conventional photographic colour film, which is a sandwich of three layers sensitive to each one of the additive colours. The blue component of the light coming from the scene will only affect the blue sensitive layer, green light will expose the green sensitive layer, and red light will expose the red one.

After processing the film it is possible to present the original, natural colours of the scene (See Figure 1.4).

There are also colour films sensitive to the near infrared radiation. In this film, the blue sensitive layer has been omitted and a IR-sensitive layer has been added. As blue (together with green and red) is necessary to achieve natural colours, we can't expect an IR-colour film to show the scene in true colours.

As can be seen from Figure 1.4, terrain features we experience as being green will show up in blue tones, red objects will come out green, while objects re-emitting infrared radiation will be represented in red. The IR-photo is often experienced as rich in red tones. This is because the healthy, green vegetation reflects a lot of infrared radiation exposing the IR-sensitive layer of the film.

If the light intensity data for the different wavebands of Landsat and SPOT discussed in the previous sections is to be presented as images this can be done as colour composites, where the data from each waveband is assigned one of the three additive colours and presented superimposed upon each other.

FIGURE 1.4 - SPECTRAL SENSITIVITY OF CONVENTIONAL AND IR-COLOUR FILMS AND RESULTING COLOURS AFTER PROCESSING

Conventional colour film	Terrain objects will be shown in	IR-colour film
Blue Sensitive	Blue	Green Sensitive
Green Sensitive	Green	Red Sensitive
Red Sensitive	Red	IR Sensitive

The most common way to present the satellite data ("standard products") is as if they were recorded on an IR-colour film, i.e. data from the green waveband is presented in blue, "red data" in green and infrared data in red. Common combinations are Landsat MSS band 1,2,4 or SPOT 1,2,3 (See Figure 1.2).

When the images are studied it is helpful to be able to "translate" the image colours to the true terrain colours in order to identify various details in the scene. The colour key in Figure 1.5 can be used to get a rough idea of the natural object colours from the standard colour composites.

FIGURE 1.5 - COLOUR KEY FOR LANDSAT AND SPOT STANDARD PRODUCTS

IMAGE COLOUR	BLACK MAGENTA BLUE CYAN GREEN YELLOW RED
TERRAIN COLOUR/ RADIATION	MAGENTA BLUE CYAN GREEN YELLOW RED INFRARED

Landsat Standard Products

Overview images or quick-looks can be ordered as small scale paper prints from Landsat registrations to check cloud cover and assess geographical location. Quick-looks are MSS products but cover the same scene as the simultaneous TM registration.

Full resolution images can be ordered as paper of film prints in black-and-white or in colours. The spectral bands can be chosen freely for each purpose and can be combined to a colour composite. Due to the highly increased number of pixels with the TM registration, TM photo products are processed only in quarter scenes. The most common scale of the MSS film originals is 1:1500,000 (quarter scene).

MSS and TM data in digital form are delivered as full scenes with all or just a spectral band represented. TM data can also be ordered covering a quarter scene. Data are delivered either geometrically raw or corrected for radiometrical and geometrical errors.

SPOT Standard Products

SPOT standard products comprise entire scenes or parts of scenes. A scene corresponds to an area with a height of 60 km and a width of 60-80, depending on whether the image is registered vertically or by an angled mirror. The scenes are identified on a predetermined grid on the Earth's surface and with latitude and longitude.

Standard products can be ordered in three processing levels:

Level	Characteristics
1A	This is basically raw data. Information from the detectors has been processed to normalize each spectral band. Coefficients for calibration between bands and absolute values are specified. No geometrical correction is included. The

instrument's viewing angle is specified. This level of processing is particularly suitable for basic radiometric studies and stereo projections.

1B The data has been corrected for systematic errors with regard to radiometry and geometry, the Earth's rotation and curvature and angle of registration.

2 A geometrically precision corrected product. In addition to the radiometric correction in 1B, the image has been corrected on the basis of maps or ground control points and presented in an optional cartographic projection. Processing is done without a digital terrain model. This means that for areas with a relatively low relief and almost vertical registration angles, a positional accuracy of 5 m can be achieved in the case of panchromatic images and 10 m for multispectral images.

Level 2 images normally have a north-south orientation and can be supplied provided that maps are available for checkpoint taking.

SPOT Special Products

In addition to the standard products above, a number of special products are available or will be in the near future:

- Merged multispectral and panchromatic data
- Scene shifted along the satellite track
- Mosaic from two adjacent scenes along the satellite track
- Mosaic from four adjacent scenes
- Quarter scene film products
- Large format film products
- Stereoscopic pairs
- Digital terrain models extracted from SPOT stereoscopic pairs
- "Level 3" geometric geocoding using ground control-points and digital terrain models to remove local distortions.

APPLIED REMOTE SENSING

Satellite remote sensing is obviously here to stay. The potential for various kinds of terrain inventories, environmental monitoring, thematic mapping, etc., can be considered huge, even more so with the expected increased technical performance of the systems in the future. The literature on handling and processing of satellite data and applications is massive.

After many years of practical work as consultants in land and water development projects, mainly in different African countries, we must however, express a definite

disappointment with the ways and pace at which satellite remote sensing is being introduced and used in various types of applied projects in developing countries.

You see them everywhere, on the ministers' walls, in governmental offices, in lecture halls and laboratories of universities, etc., enlargements of Landsat and SPOT images as decorations or items to impress the visitor. Generally the interest in satellite remote sensing technique is great and officials are enthusiastic over these new and fascinating methods to collect terrain information. But when it comes to actual, applied projects we have seen rather little of relevant practical use of satellite images or data.

During training courses and various land and water resources studies we have had reason to consider the causes for the limited practical use of this, in our opinion, very potent technique. One major factor may be the lack of balance between the push for digital, high-tech approaches and other, less fancy, but maybe more appropriate methods. The situation can be illustrated as in Figure 1.6. (see below).

Officials of departments and agencies in a developing country are the targets for a number of pressure groups. There are donors suggesting development projects and programmes and also methods and techniques to be applied. There are consultants advising and pushing activities in directors they support. There are manufacturers and distributors of equipment and data, trying to convince the potential client of the superiority of their products. Also the scientific community plays a role in this game, as they often want to be in the forefront of the technological development in order to achieve or make permanent a position.

In our opinion, several of these pressure groups have too often and too eagerly pushed the high technology end of satellite remote sensing, advocating computer-based processing and manipulation of data as the path to follow.

This approach, however, usually requires complex and costly computer systems, skilled and experienced staff, continuous upgrading of software and hardware, etc. The more sophisticated the equipment or the skill required to operate such a system, the lower the rate at which it becomes incorporated into working prices. It can be assumed that at present, a need for advanced computer handling of terrain data instead of supporting a sound progress protracts and reinforces dependence on external skills and resources in most developing countries.

Another effect of the high-tech approach is that in most developing countries, due to costs, only one remote sensing centre can be established, thus concentrating all resources there, instead of making the technique available for a large number of applications on a regional or local level.

A REALISTIC APPROACH

To make effective and rewarding use of satellite remote sensing technique in a developing country in the near future, the ambition should be to introduce and apply methods that:

- can have an immediate impact
- rapidly become operational
- require only a short period of training
- require limited investments
- can be applied not only on a central level but also regionally or even locally

It is possible to fulfil many of these requirements if much the same technique and instrumentation that is used for studies of aerial photographs is also applied for the analyses of satellite images. As air photos have long been used all over the world for topographic mapping and for various kinds of terrain inventories there exists a local competence in various aspects of air photo techniques. Most authorities and institutions working with photos are usually well equipped with viewing equipment such as stereoscopes, plotters, etc., which is also well suited for the study of satellite images.

The training needed is mainly to familiarize local staff with a basic degree in their field of expertise, with the new types of images the satellite systems provide. These people are usually eager to absorb and utilize relevant parts of the new technology in order to solve problems they face in their every day work. They are familiar with the region they are working in, its topography, geology, land use pattern, cultivation practices, etc. These are all factors that will be of great importance during the analysis of satellite images.

Utilizing existing equipment, or procuring less expensive viewing devices and using standard image products at fixed prices will keep the costs down and controllable.

Parallel to the "simple approach", a long term development of computer-based methods can take place. It is essential to follow the development in the field of digital remote sensing and exploit and apply relevant new methods and knowledge for developing projects. Of special interest in the near future is the use of personal computers for image analysis and pre-processing of images.

Instrument Setup

Figure 1.7 (see below) illustrates the instrument setup for direct visual analysis of satellite images, utilizing simple equipment such as mirror stereoscopes or stereoplots, normally used for topographic mapping.

As with overlapping air photos in a stereoscope, it is also possible with satellite images to get a three-dimensional impression. Two SPOT images covering the same area, but registered from different positions in space, will give the same effect, allowing studies of topography, slopes, landforms, etc.

With Landsat images, however, the possibilities of attaining a three-dimensional impression of the terrain are very restricted since the Landsat satellites never had a sidelooking capability. Still, the stereoscope is a great help in studying Landsat images from two different occasions. The stereoscopic vision is used to compare the two images and to identify changes in the terrain (bi-temporal studies).

A stereoscope is also a useful instrument for the study of single scenes. The resolution of the human eye (i.e. the smallest detail possible to distinguish) is doubled when stereoscopic vision is used, compared to single image viewing. Consequently, a sharper and more detailed view is obtained if copies of the same image are represented to each eye separately, than if both eyes are used for studying a single copy of the image.

The observations made in a stereoscope are usually transferred by hand to a map or onto an enlargement of one of the satellite images studied. However, this way of transference can be of less value if the map lacks details or an enlargement to a proper scale is not available. In our opinion, the transfer of information from images to a map is best and most accurately done in a stereo-plotting instrument of a type used for conventional mapping. The stereo-plotter is then used as a sophisticated pantograph, where the plotting can be done to a chosen scale.

A most useful application of the system is shown by the arrows No. 3 in Figure 1.7. A geological map, a vegetation map or any other type of thematic map can be placed on the plotting table and the reference dot in the instruments optics will fall upon the corresponding point of the images, giving an excellent and precise image location. This option can be of great value during an initial phase of a satellite image survey and maybe most important, for training purposes. The method has been described in more detail by Larsson and Hanson (1985).

Satellite images with a limited geometrical correction applied ("system corrected" images) can be used for most visual studies.

Image Analyses

As with conventional airphoto interpretation, the visual study of satellite images is an indirect way of collecting information about the surface as well as subsurface features of the ground. Conclusions on the character and properties of the terrain is drawn from the signals or the interpretation elements that we can observe in the images.

These interpretation elements can be either of a static or a dynamic character. The status elements appear much the same in the images, whether they are registered during a wet or dry season, while the appearance of dynamic elements vary with the season.

The surface drainage pattern is one example of a static element. Landforms, geological structures and alignments are others that look much the same in an image from a dry season and after a rainy period.

The appearance of various land use activities, plant cover, drainage conditions, etc., belong to the dynamic type of indicators, as they are directly affected by climatic conditions and will change over the year. Usually the static elements are best studied in a dry season image while the dynamic ones come out best after a wet period.

To optimize the output from a satellite image analysis, a bi-temporal approach can thus be useful. By using the stereoscope and registrations from two different seasons we can increase the quality as well as the efficiency of the work. Even if the colouring of the two images differ, our vision system and brain are fully capable of handling such "unnatural" combinations.

As mentioned earlier, the same technique can be used for change detection. The geometric quality of both Landsat and SPOT system corrected images is good enough to allow combinations of images registered with intervals of many years. SPOT images and a stereoscope give us easy access to a "four-dimensional" viewing as we let bi-temporal images form a stereoscopic model.

Another combination of images, which has proven to be useful in various kinds of terrain inventories, is to use one colour (SPOT XS) and one black and white image (SPOT P) registered for stereoscopic coverage. The stereoscope gives us a three dimensional view with access to colour information in one image and detailed information, due to higher resolution (10 m) in the black and white one.

More experiences from different image combinations are presented in UNGI Report number 68.1/

APPLIED REMOTE SENSING IN AN AFRICAN PERSPECTIVE

Visual Interpretation of Satellite Image

At the introduction of the Landsat system the expectations for practical applications in the developing countries were quite high. Monitoring environmental changes in areas lacking the conventional monitoring systems of the industrialized world (i.e. ground based systems, conventional remote sensing system, etc.) is one of many

important tasks to fulfil in order to cope with an increased demand on the land. Inventories of natural resources is another.

The rather low resolution of the first image products (i.e. Landsat), however, favoured the development of computer-based data analyses, based on overseas technical and human resources, whilst the local knowledge and competence concerning the land and its resources in most cases were unused in the development process. Many studies, made so far have been too academic and have had a limited influence on the practical applications and the development process. There is a risk for an overselling of the computer technology and the lack of applicable results have therefore to some extent led to a disappointment among local experts.

As discussed above, visual interpretation of satellite images can become a realistic alternative to numerical analyses, especially in developing countries. The involvement of the local competence is more easy to achieve as is the application of the results. The introduction of the new SPOT satellite, with a much higher resolution and the possibilities of stereo viewing will furthermore facilitate this approach.

It has been pointed out before that one great advantage of visual interpretation is that the same equipment can be used as for conventional interpretation of and mapping from aerial photographs. All developing countries have such facilities and, more importantly, competent staff with a good knowledge of the local conditions. By contrast, many of the computer-based studies rely on foreign equipment and personnel resources.

The practical application of visual interpretation of satellite images was developed in the developing countries because of their urgent need for rapid access to actual data for assessment of land and water resources. As a rule visual interpretation of Landsat imagery has been based either on black and white images of the various spectral bands or on interpretation of false colour composites (FCC). Bi-temporal or multi-temporal analyses are often made in order to improve the classification of the various landscape elements or monitor the annual or seasonal changes.

It is interesting to observe that the computer based processing of satellite data, developed as academic exercises in the industrialized countries, has found little practical application even there. Astaras and Lambrinos made a land systems map of Southern Greece and based their approach on visual interpretation of Landsat imagery. They conclude that visual interpretation of Landsat images "is an extension of the conventional techniques of aerial photographic interpretation, familiar to the earth scientists" that "in large areas .. satellite images are even better than orthophoto mosaics for distinguishing geological units or terrain pattern..."2/

Visual Interpretation of Satellite Images in Developing Countries

Already in 1978 guidelines developed for using Landsat data for rural land use surveys in developing countries stated that; initially, many preprocessing and interpretation techniques were considered and rejected on the grounds that they were inadequate for operational use. The suggested imagery and interpretation techniques consisting of colour composites and monocular magnification proved to be the simplest, fastest and most versatile method.3/

Hilwig argues that "systematic studies of multitemporal Landsat imagery by an experienced interpreter using limited or moderate optical facilities may result in exploratory to generalized thematic maps ranging from 1:250,000 to 1:1 million retaining high information content of terrain. The lost cost of the materials and the intermediate technology used for interpretation purposes offer particular advantages for inventories in developing countries of the world."4/

African Case Studies

Examples of African studies made by visual interpretation of satellite imagery are presented in Table 2.1. Some of the papers are quoted in the following paragraphs, together with a short comment on their achievements.

King notes that "land system analyses based primarily upon usual interpretation of Landsat imagery was found to be the most suitable rapid rural appraisal technique for estimating land resources in extensive areas. The advent of multitemporal satellite imagery has enabled a rapid technique of assessing dynamic environmental impact trends."5/

Haack asserts that "in any resource inventory using Landsat data it is important to carefully evaluate the positive analysis technique within the context of available data,information needs and existing funds, equipment and expertise. A usual interpretation of false colour composites (FCC) was inexpensive, required minimal equipment and expertise and provided good results."6/

Dunford and others working with rural development planning say that "two factors, however, persuaded us to relay on photo image products (instead of digital analyses of Landsat data), the first concerned the cost, time and uncertainty of obtaining acceptable deliverable products from digital analyses ..... the second factor was that the regional staff needed to participate in information and interpretation...".7/

TABLE 2.1 - AFRICAN EXAMPLES OF STUDIES USING VISUAL INTERPRETATION OF SATELLITE DATA

Author	Year	Aims	Type of Imagery	Area
Strömquist	1976	Land systems, soil erosion	B&W images of individual spectral bands	Central Tanzania
FAO	1977	Land systems, soil erosion	B&W and FCC images	Morocco
Johansson & Strömquist	1978	Vegetation and geo-morphology	B&W images of individual spectral bands	Central Tanzania
Beaumont	1979	Land capability, road planning	Multitemporal, FCC	NE Somalia
Breyer	1982	Land systems	Multitemporal FCC	Botswana
King	1982	Land systems, soil erosion	Multitemporal FCC	Tanzania
Haack	1983	Vegetation studies	FCC images	Swaziland
Dunford	1983	Rural dev. planning	FCC images	Kenya
Edwards, et. al.	1983	Grassburns	B&W, Band 5	South Africa
Zietsman	1984	Land use	FCC images	South Africa
Newton	1984	Geology	Multitemporal FCC and single band imagery	South Africa
Larsson & Hanson	1985	Water dev.	Bi-temporal FCC images	Ethiopia

TABLE 2.1 (continued)

Author	Year	Aims	Type of Imagery	Area
Wayumba & Philipson	1985	Land use	Multitemporal single band transp.	Kenya
Strömquist	1986	Soil erosion	Bi-temporal FCC	Tanzania
Mushala	1986	Land systems	Multitemporal single band transp.	Tanzania
Byström, et. al.	1988	Natural forests	SPOT FCC	Tanzania
Van Heist	1988	Steppe vegetation	SPOT FCC/PAN	Tunisia

Zietsman has compared digital image analysis with visual interpretation of FCC Landsat images for land use mapping of the Cape Province of South Africa. Results were compared on the basis of the relative accuracy of the map products for 10 major land use categories, as well as the real manpower inputs. When compared with a map based on aerial photography, the accuracy of the visually interpreted Landsat map was estimated at 75 per cent while the accuracy of the digitally produced map was 60 per cent.8/

Larsson and Hanson made a water resource inventory and found that "visual inspection of bi-temporal satellite images is a simple, rapid and cost effective method. One advantage is that it can be performed using existing equipment and facilities; another is that it can be handled and used by many professionals in the geo- and bioscientific fields, after only a short period of training".9/

In a South African study Newton also stressed the bi- or multitemporal options of enhancing the accuracy of the interpretation. He also compared the interband differences to map different geological features in a set of Cape province environment. He says that "it is clear...that the first stage in selecting suitable imagery for interpretation must be to formulate the purpose of the study as closely as possible, since for instance a fracture-trace investigation, for instance will require a low sun elevation, while lithological or stratigraphic study may be better served by the more even illumination during the summer." To compare the seasonal or intraband differences Newton used an ordinary steresoscope and it was found that "areas of change and or difference show up clearly as the brain tries to fuse the differing images..."10/

Strömquist, Lundén and Chakela used visual interpretation bi-temporal false colour Landsat images to produce a provisional soil erosion map of the Lesotho lowlands. The interpretation of the Landsat imagery was independently made by two persons using slightly different methods. Interpretation of enlarged images and interpretation of bi-temporal images in an advanced stereoscope (Zeiss Interpretoscope). The enlarged images from the driest dry season during the Landsat observations period (July 1983), having the same scale as the general topographical map (1:250,000), were used to produce a soil erosion map with three different erosion classes. False colour transparencies from two different dry seasons (the wettest and driest) were also used to produce the same type of soil erosion map by interpretation in a Zeiss Interpretoscope.11/

Mushala (1986) mapped the land systems of the heavily eroded Kondoa district in semi arid-Tanzania. Mushala combined visual interpretation of Landsat images and interpretation of aerial photography in a multistage mode to assess the development and spatial extend of accelerated soil erosion, and concluded that "... satellite imagery has certain unique features which are particularly useful for developing countries. A major advantage is the large area coverage of the Landsat system, which provide a good synoptic view of general assessment of the physical environment, especially geological structures, drainage patterns and vegetation characteristics."12/

In summary, the quoted comments describe the applicability of the satellite information in African environments by using the local competence in combination with visual interpretation, rather than using overseas equipment and staffing.

TABLE 2.2 - ARGUMENTS FOR USING VISUAL INTERPRETATION OF SATELLITE DATA

Author	Low cost	Rapid Access to results	Accuracy	Involvement of local staff
King	*	*		*
Haack	*	*	*	*
Dunford		*	*	*
Wayumba and Philipson	*	*	*	
Zietsman	*	*	*	
Larsson and Hanson	*	*	*	*
Strömquist et. al.			*	

TERRAIN REGIONALIZATION AND REMOTE SENSING

THE LAND SYSTEMS APPROACH

As was discussed above, a common approach to landscape assessment is to find the distribution and pattern of the physical features defining the terrain and to delimitate units or regions of a specific, uniform character. Such studies based on analyses of genesis and processes, as well a directly observable surface attributes can form part of the basis for decisions about land utilization and management.

One way to find the units forming the terrain is to apply the physiographic or land systems approach.

The land systems approach is an integrated survey, meaning that all, or several factors of the physical environment are mapped simultaneously. The origins of this approach lay in the application of air photo interpretation to rapid reconnaissance mapping. Three organizations discovered independently that boundaries drawn from air photographs could serve a variety of purposes. The Australian Division of Land Use

Research aimed to conduct a rapid appraisal of the resources of large empty areas in the north and interior of the country; the South African National Institute of Road Research, was concerned with soil engineering properties for the design of road systems; and MEXI, an experimental unit of the British Army, wanted to know whether their tanks would sink into the mud and to know the answers to other military questions. On discovering this common experience, the approach was systematized and a nomenclature established.

Two principal mapping units are employed, the land system and the land facet. The land system is an area with a recurring pattern of topography, soils and vegetation, and with a relatively uniform climate. The land facet is an area within which, for most practical purposes, environmental conditions are uniform.

Both definitions are rationalizations of units that arise naturally in the course of photo-interpretation; land systems are distinctive patterns extending across one or several photographs, while facets are the smallest areas that can be recognized and delineated. The facets within a system are not a random collection of contiguous areas but are often causally linked, by geomorphological processes, origin or groundwater flow. Hence an alternative definition of a land system is an area with a recurring pattern of genetically linked land facets.

There have been attempts at grouping the land systems into higher categories but there is no generally agreed classification.

More detailed subdivisions, land elements, are sometimes initially distinguished, then amalgamated into land facets under the qualification "for most practical purposes". One further term, land units, does not have a standard definition. As employed in Australian surveys, it is in some cases equivalent to the land facet, in others it is more generalized. Landscapes are by no means invariably divided into two hierarchical levels, and land units can usefully be reserved for cases where it seems necessary to distinguish a category between the system and facet.

Defining features

The defining features of each land system should be systematically noted. A high proportion of both defining features and boundaries are based on landforms. This is not only for practical reasons. It is desirable in principle to identify and as far as possible to define, land systems in terms of landforms in the interest of having a uniform basis to the mapping. In flat areas, for example on coastal and alluvial plains, vegetation must be used.

The identification and delineation of landform-based mapping units is nearly always done by judgement, and their description based at the photo interpretation stage on qualitative terms, e.g. "moderately sloping with closely spaced, narrow valley floors".

A parametric method is also possible. Individual elements of landforms are first measured and mapped: altitude, slope angle, profile curvature, plan curvature, aspect, basin size, etc. These are then combined to identify landform elements which are combined into landform patterns. These patterns can form the basis of land facets and land systems respectively. The parametric method usually gives a more objective and uniform basis to land system identification, but it is much slower.

Examples of the land systems mapping technique, as adapted to African conditions, can be found in several areas, representing a rich variety of landforms. The technique has been used in north-eastern Nigeria (Bawden et al. 1969), Uganda (Ollier et al. 1969), western Kenya (Scott et al. 1970), Luangwa Valley in Zambia (Astle et al. 1968), Lesotho (Bawden et al. 1968), Swaziland (Murdoch et al. 1970), South Africa (Brink et al. 1968), Tanzania (Strömquist 1976, King 1982, Mushala 1986), Morocco (FAO 1977) and Botswana (Breyer 1982).

Figure 3.1 shows an example from the land systems mapping of the Wabag-Tari Area, Swaziland carried out by Murdoch et al. in 1970.

Methods

The specific aims of the surveys are generally adapted to the actual needs of the planners, which means that some focus on agro-economical planning, while others may concentrate on general management and planning (i.e. community planning, land-use, communications etc.) or on inventories made for specific purposes such as assessments of the environmental factors etc.

As a rule, the mapping of land systems is carried out by research teams including experts in several sciences. A geomorphologist or geologist can be responsible for the division of the land into systems, as these depending mostly upon the geomorphology. According to the needs of the planners, the research teams may include botanists, soil scientists, land-use experts, etc.

Summarizing the methods used in the above mentioned investigations, it is possible to divide the land systems mapping into four different stages:

1. Compilation of existing data (scientific publications, geological and topographical maps, etc.);

2. Preliminary division of the area into land systems by using air photos, or preferably, air photo mosaics in smaller scales. The preliminary division is based on patterns identified on the mosaics and knowledge of the previous works in the area;

3. Field checks and air photo interpretation of system boundaries. Identification of soils, vegetation and land facets;.

4. Cartographic presentation of land systems and facets combined with descriptive texts, topographical sections, block diagrams, etc.

The land facets are the basic units of terrain, which in a variety of combinations and patterns make up the land systems. The facets are usually identified by air photo interpretation and limited ground checks.

In order to increase the usefulness of the land systems map, the land facets must be defined in terms of simple attributes, such as landforms, the materials (rocks and soils), and their water regimes and vegetation. In our opinion, the land facets must also, if possible, be defined in terms of the present-day active geomorphological processes. This is necessary to increase the understanding of the changing landscape and of the ways in which man affects the natural processes in a negative or positive way. The user of the land systems map must be aware of the fact that land facets do not represent static items in nature. They are representative of certain combinations of processes that change the landscapes at different rates. These rates can be increased by misusing the land and by bad planning.

If an area is subdivided into land systems and land facets, the facets within a certain system should be treated as uniform for all but the most intensive or high costs kinds of land use.

THE USE OF SATELLITE IMAGERY IN LAND SYSTEMS MAPPING

Land system surveys based on satellite imagery in conjunction with field traverses, are not as good as those based on photointerpretation but are not demonstrably very much worse. For example, air photo interpretation at 1:250,000 of part of Sudan took eight man-months per 1000 km^2, compared with 1.5 man-months per 1,000 km^2 for survey of a similar area using Landsat imagery in conjunction with partial photo interpretation. The whole of Ethiopia has been covered by Landsat interpretation at 1:1,000,000 by a small team in one year, a task unthinkable using air photographs.

Thus, the value of the results of satellite-based survey may be lower, but not by a large margin, say something like "half as good", but the cost of completing such a survey is lower by a factor of ten or more. Hence the results obtained per unit cost are certainly greater, in addition, they are obtained much more quickly. Given that the usefulness of reconnaissance surveys in development planning is limited, it may prove to be that the functions which they do serve can be achieved satisfactorily by satellite-based survey.

The initial stage, that of drawing provisional boundaries based on the satellite imagery, does not differ in principle from air photointerpretation. Patterns of inferred landforms and land cover (vegetation/use) are identified and delimited. Their provisional description is more inferential and tentative than from stereoscopic viewing of air photos, leaving more detail to be added or modified at the stage of field traversing. A nested procedure combining complete coverage by satellite imagery with conventional photointerpretation for sample areas is now often the best way of conducing reconnaissance surveys.

Strömquist made a land-systems map of the Great Ruaha catchment in central Tanzania. The drainage basin is about 65000 km^2 large and the only possible practical way to construct a land systems map was to use satellite imagery. He found that the detailed information obtained from the satellite images varied with terrain factors, relief and vegetation. The most detailed geomorphological information could be obtained form open spaces like grasslands and wooded, low relief areas, where the small scale geomorphological items (i.e. land facets) can hardly be distinguished from the intensive signals from the vegetation cover13/.

According to this study, the greatest advantage gained by using satellite images, instead of conventional air photo mosaics for land systems mapping, is that the same colours prevail over large areas representing the same type of terrain or vegetation. The colours are good indicators of soil types and drainage conditions due to differences in moisture content and vegetation. SPOT satellite images have later been tested for land-systems mapping of the same area and the stereo option has furthermore enhanced the interpretation of the land systems and the subdivision of the systems into land facets.

The Catchment Approach

Regionalization described in the previous section involves subjective decisions, and there is a natural tendency therefore to search for more repeatable, objective procedures. One alternative of definite interest for terrain analysis involves the use of morphotometric units defined either from remotely sensed data or from topographic maps.

The most frequently used type of morphotometric subdivision of terrain is the drainage basin or catchment. The principal adage of catchments as terrain regions is that they are functional units within which many land properties and processes have distinct spatial arrangements. In order to make comparisons possible between different drainage basins various methods of stream and basin labelling have been suggested. The most commonly applied is the Strahler ordering system (See Figure 3.2)

A "catchment approach" is applicable in many planning, exploitation and monitoring situations because a downstream section of a river is affected by what occurs upstream. It is often necessary to survey an entire drainage area in order to be able to

foresee the effects of any upstream activities, rather than restricting the study to a limited part of the basin.

Although apparently an attractive system, the catchment has some limitations as a practical unit for storage of land information. One such limitation is, for example, that the scale and the resolution of the data source (air photos, satellite images, maps, etc.) has a strong effect on the number of streams detected and hence on the demarcation of the drainage basin.

Regular data service

Instead of using physiographic schemes for collecting and storing data, an alternative is to subdivide an area by a regular grid and thus create an array of regular areal units for these purposes. The use of regular units defined by regular grids has the advantage over physiographic and geomorphological regionalizations of subdividing terrain into units with exactly the same size, which aids comparison between different areas. On the other hand varying land complexity may demand variable grid sizes, an approach which usually is not recommended. Choice of the most appropriate cell size still remains a difficult problem.

Unsupervised classification of regular arrays of remote sensing pixels and other terrain data stored in cells usually produces regions of quite different types from physiographic ones described earlier, since they are solely dependent on the values of properties at each individual cell rather than on the spatial organization of properties. Inventories based on this approach have been used in soil erosion surveys identifying areas belonging to different soil erosion classes, estimating environmental hazards or for assessing land use.

The size of the grid net has to be adapted to the scale of the aerial photograph and the resolution of the satellite image. In a Lesotho study (Nordstrom 1989, Strömquist et al., 1985 and 1988) and in studies made in Tanzania it was found practical to use 1 cm^2 squares on overlays on aerial photographs in scales ranging from 1:20,000 to 1:30,000 and the same grid size for SPOT scenes enlarged to a scale of 1:100,000. The data presentation, after the inventories, can either be represented on a map using conventional cartographical methods or by loading the data in a conventional spread sheet programme for a personal computer, where each cell represents a cell on the grid covering the image.14/

Such an approach has recently been tested in a land-capability study. In this study the data was stored in Excel, which is a spreadsheet programme with programming language and database capabilities. The original data was stored in columns and rows where the cells represent the 1 x 1 km^2 cells used for the inventory. A data base was created which enabled possibilities to combine the physical data of different levels with the data on human land-use. The results were plotted as reference

maps of the different combinations where the database capabilities of the spread sheet programme (Excel for the Macintosh) were used to compare and compile different data in each cell. Hence the spreadsheet programme was used as a geographical information system (GIS), normally requiring mainframe computers.15/

ENVIRONMENTAL MONITORING

Classification of Soil Erosion

Assessing soil degradation has become one of the most important tasks in an effective planning of land resources in developing countries. The results of erosion surveys are often presented as erosion maps of an area or a region. According to Bergsma, there are three major groups of erosion maps. Each group overlaps to a certain extent the other two.16/

The first group shows erosion features and reflects to some extent the present rate of the erosion processes. The second group takes into account past rates of erosion by studies of soil profile changes whilst the third group are maps illustrating possible erosion hazards (See Stocking and Elwell 1973, Millington et al. 1982, SADDCC Soil and Water Conservation and Land Utilization Programme 1986, Chakela 1988.) A fourth type of maps are those based on sediment yield of rivers, mostly produced on a global or regional scale.17/

Only the latter type reflects seasonal or annual variations in sediment yield or production while the other approaches the sum of past and present events, hence giving a synoptic view of the present status of the land rather than actual process rates or hazards.

The importance of assessing soil degradation has forced the FAO to start a project on mapping soil degradation.18/ The aim of the FAO project is to produce a world map, mostly based on a compilation of existing data and maps.

Many areas in the developing countries, however, lack access to good background data needed for the compilation of an FAO-type soil degradation map. Remote sensing data or figures of sediment yield in the main rivers have therefore become realistic alternatives in obtaining background data for the construction of erosion maps.

The FAO in 1978 also suggested the use of Landsat imagery in their erosion mapping project, but experiences from a pilot study in Northern Africa reduced its use to delineate the land systems which are sufficiently homogeneous with regard to relief, climate, vegetation, soil and land use. The practical mapping should, according to the FAO, be carried out by field surveys and air photo interpretation.

Satellite data has, however, become important as a source of information during the last years. The visual interpretation approach has become the only practical solution to the problem.

All erosion classification systems based on visual interpretation of Landsat data for practical reasons use classification systems divided into a few classes. Air photo interpretation based classification systems or systems based on field studies allow for a further subdivision into more classes. In the study of soil erosion in the Lesotho lowlands. A 1988 study linked the three observable erosion classes with the existing SARCCUS system, which is based on air photo interpretation.19/

TABLE 4.1. - AFRICAN EXAMPLES OF CLASSIFICATION/OR IDENTIFICATION OF SOIL EROSION BY REMOTE SENSING OR FIELD SURVEYS.

Author	Erosions Classes	Based on/Study Area
Strömquist, 1976	LOW, MODERATE, HIGH	Landsat images (B&W)/central Tanzania
FAO 1977	SLIGHT,MEDIUM,HIGH	Landsat for land systems and USLE factors for intensity of ominant process/Morocco
Makhanya, 1977	MODERATE, SEVERE, VERY SEVERE	Air photos, Gully erosion/Lesotho
Gil, 1979	SLIGHT, MODERATE, HIGH	FAO recommendations for classification using air photos
Dunne et al. 1981	0-6 (no sign-badland)	KREMU recommendations for Kenya Rangelands, air photo, field surveys/Kenya

TABLE 4.1 (continued)

Author	Erosion Classes	Based on/Study Area
SARCCUS 1981	NO APPARENT, SLIGHT MODERATE, SEVERE, VERY SEVERE	Air/Photos/Southern Africa
Garland, 1982		Panchromatic and infrared air photos/South Africa
Withlow, R., 1986	NO APPARENT, SLIGHT MODERATE, SEVERE, VERY SEVERE	Air photos Application of SARCCUS method/ Zimbabwe
Strömquist et.al. 1986	LOW, MODERATE, HIGH	Landsat, FCC/Lesotho
Mushala 1986	WEAK, MODERATE, SEVERE	Landsat, FCC/Tanzania
Strömquist et.al. 1988	SARRCUS 5 classes	SPOT/Lesotho (see Whitlow)

As the first erosion studies, based on visual interpretation of satellite data, used classification systems where erosion, for practical purposes, only could be divided into a few classes, some of the early erosion maps were based on digital analyses of data using computer-assisted classification in combination with rough estimates of soil loss according to different soil loss equations, such as the universal soil loss equation (USLE). This approach, however, gives a false impression of accuracy, both because of the equations (based on plot studies with a specific slope length etc.) and the difficulties in making an automatic classification of erosion features.

In a study made in the Lesotho lowlands, however, Strömquist et al. tested various combinations of SPOT imagery to map soil erosion according to the Southern African system (SARCCUS) for erosion classification based on air photos.20/ The approach was fruitful and it was possible to differentiate all of the five sheet erosion classes identified on air photos. This pilot study envisages a new practical approach of monitoring soil erosion from satellite data as the visual interpretation of SPOT imagery is directly compatible with existing classification systems and previous information based on air phone.

Erosion hazard assessment

Analyses of erosion risk is a procedure aimed at describing the physical danger of soil erosion over large areas. Estimates of erosion hazards normally include the observations of a range of factors of erosion, such as rainfall erosivity, soil erodibility, and vegetation cover. The methods also considers which variable best describes each factor's influence on erosion, plots the individual spatial distributions of each variable and then combines them to estimate an overall hazard (See Stocking et. al. 1988).

In a method developed for the SADCC countries the estimates of the erosion hazards are strictly based on physical data of rainfall erosivity, soil erodibility, vegetation cover/type of land use and topography (with the information of relief data compiled from topographical maps). Erosion hazard maps are being produced in the SADCC countries, showing the potential risk areas on a map of each country. The practical application of this technique can, however, be discussed especially if one is interested in a rapid assessment of the hazard within smaller project areas or within areas lacking accurate physical data of soils, topography and rainfall. In such cases remote sensing applications are recommended.

In a recent Tanzanian study of the environmental hazards of the Mtera hydro-power project (Strömquist 1988) the erosion hazard assessment was based on interpretation of SPOT satellite imagery in combination with limited field checks.

The SPOT satellite images used for the analyses in that study were stereo transparencies (False Colour Composites, FCC) in the scale of 1:400,000. The interpretation was made in an advanced stereoscope and the plotting of the results was made on transparent film overlays covering enlarged images at a scale of 1:100,000.

The drainage net was mapped down to the first order gullies, the geomorphological units (land systems, land facets) were mapped in relation to their importance as sediment sources, deposition zones, and areas of temporary sediment storage.

The classification of erosion intensity was based on the South African system developed for use with air photo interpretation.21/ This system has later been modified for use with satellite images.22/ As sheet erosion is the erosion type that is most easily detected on the satellite scenes, because of exposure of highly reflectable subsoil or sediment deposits on the fields, it was natural to concentrate the inventory to this erosion type only. The classification and interpretation was related to a grid of 1 x 1 km squares represented on a transparent overlay. It was possible to retain the original five erosion classes due to the high resolution of SPOT images. Therefore, the soil erosion is described in terms of five classes of erosion as described below.

Class	Characteristics
Class 1:	None apparent. No visible signs of erosion. Level of management appears to be high.
Class 2:	Slight. Areas of erosion (light-blue tone) observed on the images. Erosion deduced from poor cover, sediment deposits and plant pedestals (as observed in the field).
Class 3:	Moderate. Eroded areas obvious on the images. Plant cover is very poor and the sediment deposits are extensive. Associated with small rills (as observed in the field).
Class 4:	Severe. Sheet erosion of such severity always associated with rills and gullies. Much of the A-horizon has been removed.
Class 5:	Very severe. As class four. Erosion type makes up most of the unit area. Associated with gully erosion class 5.

Two new classes were added indicating different accumulation or temporary sediment storage areas. Class I represents sediment storage on colluvial slopes and Class II floodplain deposition, alluvial fan deposition or braided outwash deposition.

Environmental hazards threatening the environment of the reservoir region are related to land use changes causing vegetation and soil degradation which result in an increased sediment yield to the reservoir. The bulk of sediments transported into the reservoir is, however, in this case transported by the main rivers. Estimates based on a previous water sampling programme give an annual sediment input to the reservoir of 4×10^6 tonnes.23/

In the SPOT study, maps have been produced of the drainage net (streams and gullies), geomorphological units and sheet erosion intensity (by visual interpretation of SPOT imagery. To estimate the management hazards for the reservoir region, a factor scoring analyses has been made based on results of the thematic mapping. The following classes were used for the different classes (as shown below).

Drainage net:

1. Areas with closed drainage, drainage to areas upstream from the major sedimentation areas etc.

2. Drainage through channels (gullies) with a direct input to rivers draining directly into the reservoir.

3. Areas with high drainage density (e.g. gullied land) with direct drainage into the reservoir.

Geomorphic units:

1. Alluvial fans and braided complex, colluvial slopes, areas of recent river sedimentation.

2. Ancient lake beds (silt over sand) close to present day reservoir, Plateaux areas with residual soils. Pediment surfaces with sandy and silty soils (colluvium).

3. Escarpments and residual mountains. Eroded pediment surfaces with sandy and silty soils.

Erosion intensity:

1. Erosion class 1, deposition class I and II.
2. Erosion class 2 and 3.
3. Erosion class 4 and 5.

Environmental hazard score:

O-5: Low
6-8: Moderate
>.9 High

RIVER BASIN DEVELOPMENT

Man's use of land and water resources and the development of rivers are bound to cause technical and environmental problems. Land will be flooded and hydrological regimes altered. There will be consequences for vegetation and wildlife, man and his livelihood.

A river basin is an ecological unit where erosion and sedimentation problems in a certain region often have implications for the river basin (catchment area) as a whole. As an effect of changes in land-use of the drainage areas of rivers, an increasing amount of material will often be discharged into the river network from erosion of the land in between the channels. Soil erosion of the land produces sediments that are washed into the river system by overland flow and through the gully system. Some of the eroded material will be deposited close to the source, i.e. at the base of steep hillsides or on the lower parts of the slopes. Other particles will be transported further downstream in the drainage system and deposited on low gradient flood plains or on frequently flooded valley floors while other materials will be deposited within delta areas, lakes or artificial reservoirs. The river itself erodes the land by riverbank erosion and by erosion of its

bed. All the eroded material is transported by the river, either as bed-load (i.e. the coarser material transported more or less in contact with the river bed) and as suspended load (i.e. the finer fractions).

A river also transports dissolved chemicals supplied by the soil forming processes and transported into the river by ground water drainage. Part of the chemical load also originates from industrial and domestic waste and fertilizers polluting the ground water of farm lands in the catchment area.

Environmental Impact of River Regulation

Stream regulation is part of the technology aimed at a more efficient use of the water resources. In most cases river regulation is made for hydropower development but in other cases a more integrated river regulation is forwarded in conjunction with water resources development projects such as irrigation, flood control and water supply to communities, etc.

When dealing with environmental impacts of river regulation it is important to take into account several simple fundamental concepts:

1. Climatic control

The rate of most river processes is directly or indirectly controlled by climate. Water discharge, sediment production, sediment transport and seasonal variations of run-off and transport are such examples that are directly or indirectly controlled by climate.

2. The concept of a drainage basin as a fundamental ecological unit.

As the processes in any section of a river are dependent on the upstream conditions in the catchment and in the stream channel itself, changes in one part of the system will influence the others.

3. Water-sediment system and biological life.

In natural rivers there is a balance or semi-balance between water discharges and sediment load. This balance can be changed by man's influence on land-use or by changes of the catchment vegetation cover as there is an intimate relationship between biotic and abiotic factors in a river system. The natural cycle of high and low water has furthermore created and maintained the fertility of flood plains. The productivity of natural flood plains is, both in terms of agriculture and as fish breeding areas.

Impounding water in reservoirs will affect the natural river sediment system in several ways:

1. The bed-load material and parts of the suspended load will be deposited upstream the dam.

2. Evaporation (and evapotranspiration losses from aquatic vegetation) in combination with a long residence time of the water in the reservoir will increase the salinity of water and the flocculation of sediments increasing the reservoir sedimentation.

3. The deposition of sediments in the reservoir will increase the down stream erosion along the river as the competence to erode and transport increases after deposition. The sedimentation will furthermore reduce the life-span of the reservoir. It has been estimated that 95-99 per cent of the inflowing silt will be retained in large reservoirs.

Impounding water in reservoirs will affect the water quality, both downstream and in the reservoir itself. In the reservoir the water retention time (depending upon the operating regime, evaporation, etc.) will influence the quality of the water which will influence the primary biological production or indirectly as a source of food for the fish and other animals. The water quality is also dependent on other factors such as the characteristics of the river water entering the reservoir, the flooded soils and vegetation, the depth and climatic factors. The downstream impact on water quality depends on whether it originates from (i.e. the level of tailraces and outlets) above or below the thermocline of the reservoir. Surface water may be poorer in nutrients and richer in blue-green algae. Bottom water may on the other hand contain high concentrations of dissolved nutrients and is occasionally deoxygenated and laden with hydrogen sulphide.

An integrated planning approach of both the river development scheme and the upstream catchment area as well as of the downstream river sections is therefore strongly recommended.

PRINCIPLES OF MONITORING ENVIRONMENTAL IMPACT OF RIVER REGULATION

Environmental monitoring and ecological studies of river impoundment can identify and describe a number of actions which should be considered before, during and after construction of the dam. Environmental monitoring of the changes has to be done directly in the field or, for some of the study objectives, indirectly by other methods such as remote sensing.

In any river development scheme it is important to plan for the future both before and during the construction, as well as when a reservoir has been filled to its full supply

level and the commercial operation has started. The planning before the construction includes a documentation made in such a way that future changes can both be predicted and monitored. A monitoring system should furthermore monitor the changes in such a way that the impact during the construction phase could be differentiated from long-term changes.

The following objectives could be studied:

1. Geoecology of the upstream catchment area.

Such studies must include documentation of geomorphology and geomorphological processes (i.e. soil erosion, drainage, slope) climate and hydrology (of climate control of processes), vegetation and land use. All factors that are important for assessing erosion and environmental hazards (influencing the reservoir and water quality).

2. The reservoir and the reservoir region.

Such studies must include studies of the morphology and water level fluctuations, land degradation of the surrounding areas, shoreline development (important for water related diseases and the human environment) reservoir sedimentation, water quality and aquatic vegetation.

It is impossible to tell with certainty what kind of aquatic vegetation will develop in a reservoir. Vegetation development is dependent on a large number of interacting ecological factors, e.g. pH of the water and mud, dissolved nutrients and oxygen, water temperatures, wind and waves, and annual draw-down of the water. However, it is safe to predict that the aquatic vegetation will undergo a number of stages in developing towards some kind of equilibrium. The establishment of a "stable" aquatic vegetation will take a long time, and will be influenced mainly by the sized of the draw-down for a number of consecutive years, but also by the annual fluctuations in the water level. The two most influential factors are the rainfall and the regulation requirements, both of which are unknown or impossible to predict.

An aquatic plant may be called a weed when it starts to cause problems, e.g. with regard to the storage and engineering operations of a reservoir or its multi-purpose use.

The explosive growth of aquatic weeds during the first years of a man-made lake, as experienced in Lake Kariba and Lake Volta, has been linked to a high level of nutrients in the water, originating from flooded decaying organic material submerged in the water. The most troublesome aquatic weeds are the free-floating plants which often form densely interwoven mats.

3. The downstream areas.

Items to monitor are related to morphology and sediment transport (i.e. how the changed water regime influences river bank erosion and sediment transport) and in some cases how does the reduced sediment transport and changed water regime influence on coastal areas, downstream floodplains, and water quality.

The aquatic environment, or the changed aquatic environment is important for the development of several diseases in Africa. It is also important to monitor the changes in the environment. For instance, the mosquitos which breed in water are the transmitters of malaria and filaria diseases. The black flies (Similium sp.) which also breed in water, are the transmitters of the river blindness disease.

The bilharzia disease is facilitated by the presence of an aquatic snail which serves as a host for the parasite itself.

More indirectly, the water may also influence the occurrence of diseases. For instance, if the vegetation changes, due to the presence of water, and a thicker vegetation develops, it may serve as a suitable habitat for the disease transmitting tse-tse files.

REMOTE SENSING APPLICATIONS IN MONITORING ENVIRONMENTAL IMPACT OR RIVER REGULATION

In ecological impact assessments of larger water development schemes in Africa remote sensing applications have been found most useful (either alone or in combination with field methods).

Any preinvestment study has to include a documentation of the preimpoundment conditions such as the catchment characteristics (surveys of the landscape in terms of land-systems, drainage, erosion status and hazards, present vegetation cover and land-use. Satellite remote sensing has been useful in assessing the catchment environment and nearshore environment of the reservoirs. Photogrammetric methods are essential to map the impounded area in order to assess water storage and future environmental consequences (i.e. developments of future sedimentation areas, water retention areas, shoreline types and vegetation).

Satellite remote sensing (and conventional air photo interpretation) has furthermore found its applications in monitoring the catchment changes (upstream and downstream) after the impoundment, the spread of aquatic vegetation as well as identification of health risk areas (i.e. areas with stagnant water).

FIGURE 1.1

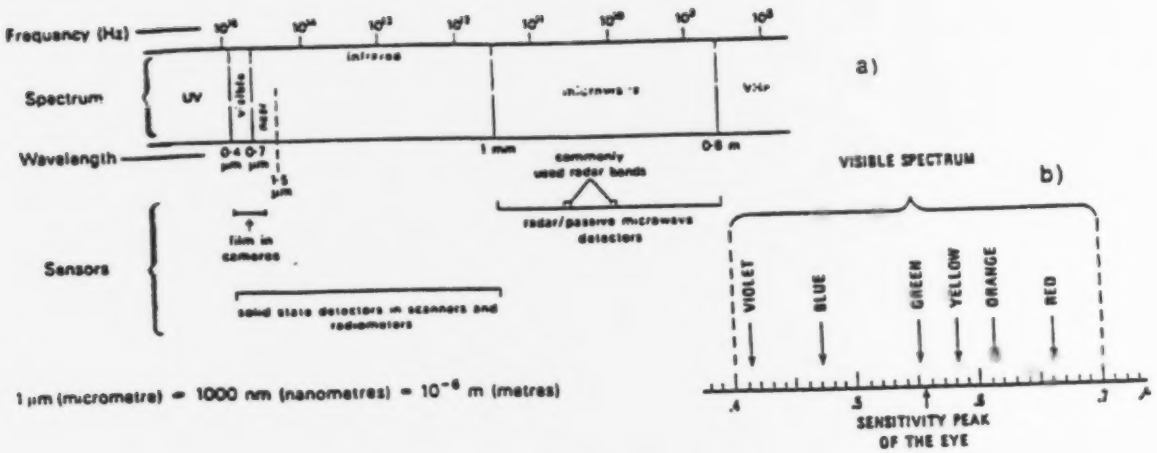


FIGURE 1.2

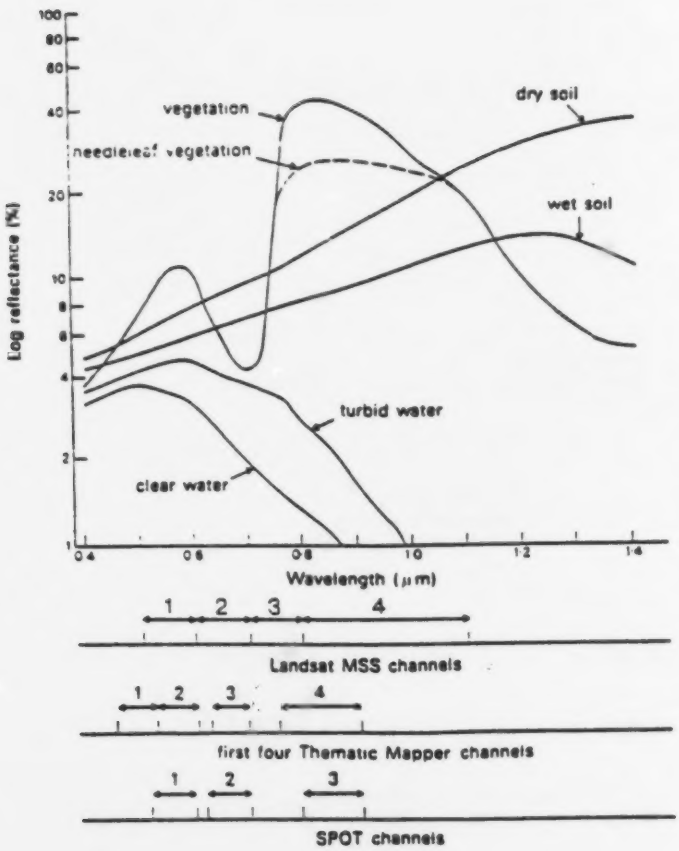
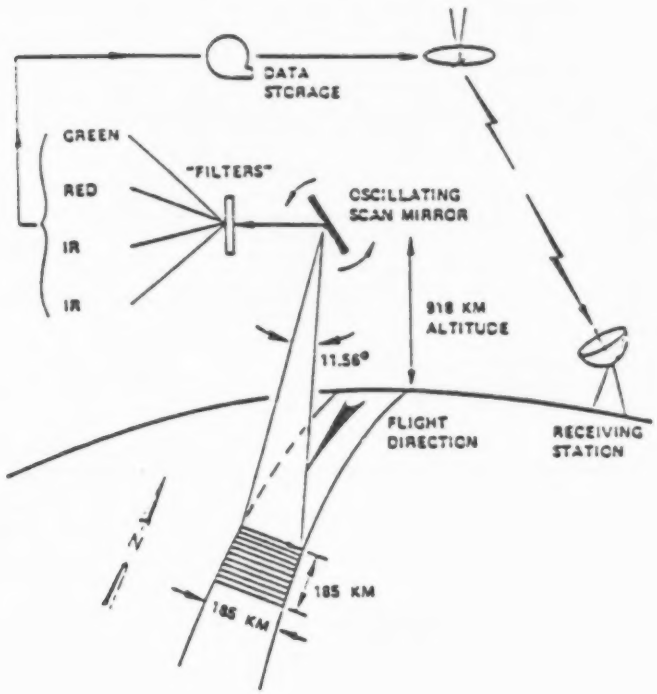
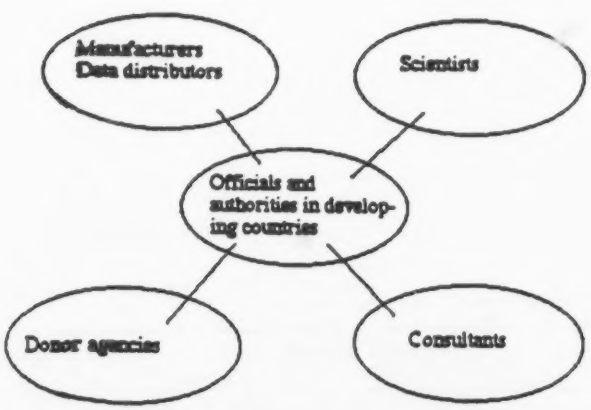


FIGURE 1.3



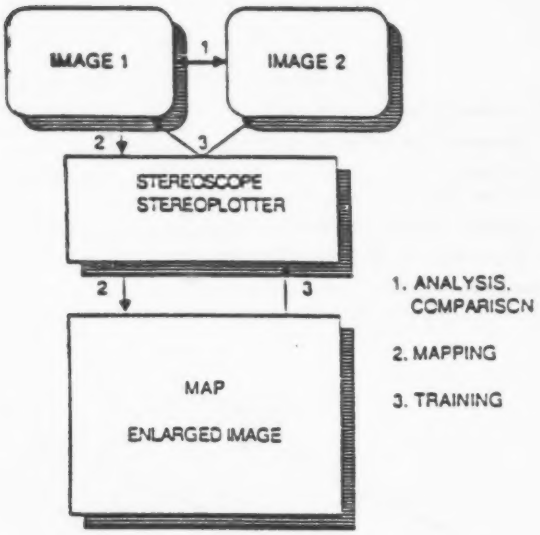
Landsat multispectral scanner (MSS). For each terrain scene, four images are transmitted to a receiving station.

FIGURE 1.6



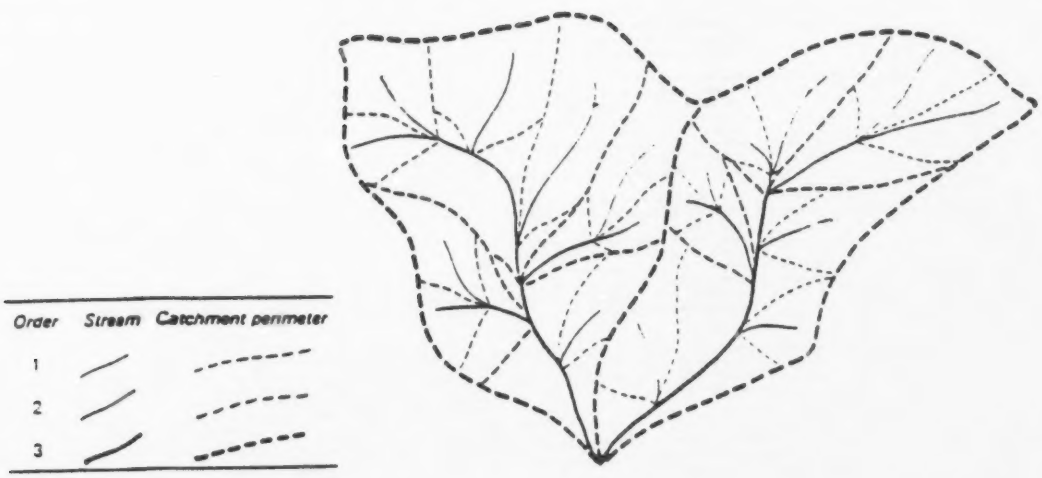
Remote sensing pressure groups.

FIGURE 1.7



Satellite image analysis and mapping set-up.

FIGURE 3.2



Ordering of river catchments using the Strahler system

FIGURE 3.1

(1) KAIENDE LAND SYSTEM* (720 SQ MILES)

Mountains and escarpments on limestone.

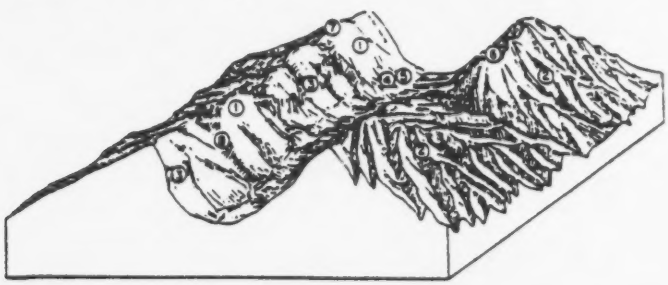
Geology.—Subhorizontal to steeply dipping Tertiary and minor Mesozoic limestone; locally Pleistocene ash.

Landscape Description.—Parallel mountain ridges and escarpments, mainly sharp-crested, locally slightly bevelled. Undercut valley walls.

Landscape Dynamics.—Apparently subject to rapid solution and minor rock slides. Rapid slumping of ash cover.

Altitude.—3500–11,500 ft. Internal relief up to 3000 ft.

Population and Land Use.—1800 people concentrated on 76 sq miles of land used for cultivation (mainly parts of units 4 and 5, but very small parts of most units are gardened in heavily populated parts of the area).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Normal steep slopes, rectilinear, 35–45°, and up to 200 yd long, partly with debris cover or outcropping rock	Much outcrop with humic brown clay soils of Vakari family, minor shallow dark clay soils of Kaiende family	Lower montane rain forest (beech, oak, and mixed). Gardens and garden regrowth. Sword grass and shrub regrowth. Minor montane rain forest	VIII
2	Large	Dip slopes and chevrons, rectilinear, 15–45°, and up to 2000 yd long, partly with debris cover, partly with outcropping rock	Humic brown clay soils of Vakari family with outcrop, minor shallow dark clay soils of Kaiende family on the steepest slopes		VIe–VIII
3	Medium	Precipitous slopes 40–90° and up to 500 yd long; bare rock surfaces on slopes of more than 70°	Much outcrop with shallow dark clay soils of Kaiende family and stony humic brown clay soils of Vakari family	Bare rock or sword grass and shrub regrowth. Lower montane oak and beech rain forest	VIII
4	Small	Slightly concave scree slopes 25–35° and up to 300 yd long; locally hummocky with boulder-covered surfaces	Bouldery humic brown clay soils of Vakari family with stony shallow dark clay soils of Kaiende family	Gardens and garden regrowth. Sword grass and shrub regrowth. Lower montane beech or oak rain forest	VIIe
5	Small	Colluvial aprons with slightly concave slopes 4–20°, up to 200 yd long	Humic brown clay soils of Vakari family, minor reddish clay soils of Herep family		IIIe and VIe
6	Small	Enclosed depressions up to 100 yd wide and 250 ft deep, mainly with very steep side slopes; solution shafts with near-vertical rock walls	Humic brown clay soils of Vakari family	Gardens and garden regrowth. Sword grass and shrub regrowth	VIe
7	Small	Ridge crests up to 50 yd wide alternating 30°, irregular, solution-derived microrelief	Outcrop and shallow dark clay soils of Kaiende family with humic brown clay soils of Vakari family	Lower montane beech or oak rain forest. Locally gardens and garden regrowth. Sword grass and shrub regrowth	VIII
8	Small	Dry gullies up to 200 yd wide, with steep side slopes 30–55°, floor slopes 10–45°	Humic brown clay soils of Vakari and Nenia families with shallow dark clay soils of Kaiende family and rock outcrop on steep slopes	Sword grass and shrub regrowth. Remnants lower montane beech or oak rain forest. Minor gardens and garden regrowth	VIII

*Comparable with Elimbari land system of the Goroka–Mt. Hagen area. Unmappable inclusions: Nemei, Sumi, Amoum, Anzabare, and Kaugel land systems.

Example of land systems mapping from the Wabag-Tari Area, Swaziland

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THE SATELLITE SOLUTION TO PEOPLE CONNECTIVITY*

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INTRODUCTION

The theme for this session, Modernization Through Communications-Developing a Communications infrastructure, is a topic which is central to the plans and aspirations of many of the world's countries. It is a fundamental nature of man to communicate with others; it is the single element that separates man from only surviving to evolving. The topic of defining and developing a communications infrastructure is one which often sparks spirited debate, but in all cases, touches the sense of deep commitment to progress.

My presentation is "The Satellite Solution to People Connectivity." My purpose is to provide insight into current satellite-based technology solutions for meeting humanity's need to interact with others, focusing on the concerns of administrations tasked with this responsibility.

So, it is from this perspective that I join you here today at this symposium. I hope to impart on you the current capabilities that technology has brought to the world for satellite-based communications systems, attempting to meet and exceed humanity's need to interact with others.

Unfortunately, in many, many telecommunications-based symposiums, the majority of the focus is on the presentation and discussion of technology that is still out of the reach of many. While our experts discuss world standards for global connectivity, millions of developing countries are still without basic telephone service. Phone densities in many areas of the world average fewer than five phones per 100!. All told,

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* This paper, which was presented at the United Nations/IAF/COSPAR/AIAA Symposium "Space Technology in Developing Countries-Making it Happen", held at Washington, D.C., USA, 28-30 August 1992, does not necessarily reflect the views of the United Nations.

there are still billions of people who cannot easily communicate outside of their immediate geographies.

For many of these areas, the implications of poor telecommunications services are wide-ranging. These areas are often removed from major population and economic centres, and as such, they fall lower in priority. The difficulty in justifying telecommunications investments have traditionally been attributed to the following factors:

- The comparatively high capital requirements to reach remote areas;
- The difficulty in quantifying benefits; and,
- The low rates of return which characterize these investments.

However, telecommunication services are needed to provide:

- Diversification of economic activity;
- Increased local employment opportunities;
- Increased literacy and labour force skills;
- Improved education and health care services;
- Enhanced interaction between communities and governments; and
- Compensation for unfavourable geographic or climatic conditions.

As more studies are implemented and the results of collected data are published, a clear trend appears in the correlation between improved telecommunication services and national development. Increased investment in telecommunications is one vital factor to improved GDP, and re-investment of capital in additional infrastructure and services has an additional incremental effect.

With data to support the benefits of improved telecommunications, administrations must establish the appropriate criteria for evaluating potential solutions. This, in itself is no small challenge. Administrations must consider a number of factors, each of which have a tremendous range of implications, including, financial/economic geopolitical and governmental.

As administrations plan support for addressing this requirement, a number of physical challenges make the traditional terrestrial solutions more difficult. These constraints include:

- Sparse population,
- Widely dispersed settlements,
- Rugged terrains,
- Lack of supporting infrastructure, especially adequate roads and power supplies, and
- The need of compatibility with an existing national network.

In addition, there are considerations which relate to the type of service to be provided and the ability to maintain and manage that service. These considerations include:

- Locations
- Maintenance
- Traffic volume
- Power
- Transmissions
- Installation
- Traffic type
- Plant
- Compatibility

Without adequate telecommunication services, the economic, social and cultural development of these remote areas will lag. Even when economic justification is achieved, these and other complexities have slowed the progress. Historically, terrestrial systems, which easily connect densely populated areas, failed to effectively satisfy requirements for remote areas. Fortunately, advances in satellite communications technology have allowed major development programmes, designed to address the telecommunication requirements of such special areas, to gain prominence in the national development plans of these countries.

SATELLITE COMMUNICATIONS FOR REMOTE AND RURAL AREAS

Over time, a growing number of these countries and their administrations have identified satellite communication systems solutions as the most desirable approach to overcome the above-listed barriers. The technology has consistently proven itself to be an ideal solution to issues faced by these administrations, namely:

- Large number of subscribers that are geographically widely dispersed;
- Communication demands are mainly between an urban centre and its remote areas (a star-type configuration);
- Problems with other radio-based systems that are difficult to coordinate due to frequency limitations, allocations, distances, interference, and other constraints;
- Potential of satellite for economies of scale with the ease of expanding the system to meet additional demand for services;
- Short implementation schedule for implementation of services; and
- Requirement for portable or transportable communication systems.

Other factors have also played a significant role in the acceptance of satellite communication systems particularly that continued refinements and new applications-

oriented developments have been on-going in both satellites and satellite earth station equipment over the past two decades.

New satellite access techniques have given users the ability to utilize satellite channels more efficiently and manage telecommunications traffic more effectively. The expanding offerings of global/regional satellite consortiums/carriers have certainly played a major role. These consortiums have allowed administrations to access new or expanded services, like digital services, and have introduced competitive markets.

In our on-going efforts, however, it's important for the suppliers of earth station equipment to consider the administration's perspective when looking for new solutions to the development of communications infrastructures relative to the design and development of new products. Their requirements are in a constant state of change.

Certainly the basic need to connect remote areas is unchanged, but the justifications are more complex. More administrations now view telecommunications investment as a business and marketing endeavour, and with this changed perspective comes greater fiscal accountability for investment decisions.

Satellite technology gained acceptance because it was able to overcome the imposing physical challenges. Its ability to overcome fiscal challenges has further ingrained its role as a solution of choice due to the following factors:

- New satellite technologies and applications;
- Increased manufacturing volume and reduced cost of components have allowed less expensive satellite communications solutions;
- The potential for new revenue for administrations has emerged as an important justification for satellite-based services. Lower equipment and space segment costs are now giving administrations the ability to operate at effective profit margins; and
- Increasing trends of these administrations towards privatization.

These, among other factors, have played a significant role in the emergence of satellite communications as the optimal solution. However, the advent of technology has given life to another, more powerful influencer, which has created even greater justification towards satellite-based communications systems.

THE IMPACT OF DIGITAL TECHNOLOGY ON SATELLITE COMMUNICATIONS

Much of the ability and success of satellite communications to meet today's needs results directly from the impact of integrating digital technology with satellite

communications technology. From integrated circuits to microprocessor control, digital technology has been a major force in the design and developments of new satellite communication equipment and systems.

At the product level, major improvements have been made in satellite modems and voice channel units, to name just two examples. With the implementation of Digital Signal Processing (DSP) technology, satellite modems are able to achieve consistently higher performance levels. Implementation of digital components has additionally removed labour intensive tuning accompanied with analog-based products. Most importantly, especially in light of the previous discussion, the product cost has been substantially reduced — by as much as 50 per cent compared to just five years ago.

DSP technology has also played a significant role in expanding the satellite channel capacity of voice circuits. New voice channel units, utilizing the benefits of DSP, are allowing low-bit-rate coding of voice circuits, thereby multiplying the effective number of voice circuits that may be placed within a satellite channel. Multiplication factors greater than five are commonplace, yet the end-user hears no discernable degradation to voice quality.

This new generation technology is more efficient and also consumes less power. Additionally, this technology has allowed major product advancements relative to application flexibility, e.g., variable-rate modems which can be user-configured to meet changing requirements.

Other system components are designed with more internal software, allowing automation of previous user-dependent functions. In satellite network management and control, a software-based system can automatically monitor and control voice and data traffic, provide dynamic allocation of bandwidth, and provide fault detection and alternative traffic routing.

Not to be overlooked is the wide range of digital services now available from satellite consortiums and carriers. Services such as INTELSAT's International Business Service (IBS) and Intermediate Data rate (IDR) services add substantially to the cost-effectiveness of the satellite channel. They also give users added flexibility, allowing them to purchase smaller increments of digital capacity.

The greatest benefit of the use of digital technology is its impact on the design and complexity of satellite earth station products, resulting in less costly products.

NEW GENERATION TECHNOLOGY: DIGITAL SATELLITE EARTH STATIONS

The combination of changing market dynamics and the integration of digital technology has led to new solutions for connectivity of remote/rural areas. These forces have created a powerful new generation of satellite earth station technologies.

The benefits include lower cost and higher performance, the ability to build telecommunication infrastructures based on emerging digital standards, such as ISDN, and finally, a clear migration path for administrations to gravitate to increasingly sophisticated services.

However, major questions and issues remain. Specifically, what solutions are provided by this new generation of satellite technology? How do the new digital earth stations integrate with existing telecommunication infrastructures? What services can be supported and at what cost?

To answer each of these questions would require detailed knowledge of specific needs and goals. Unfortunately, the timing of this presentation wouldn't allow such a business case analysis. However, basic applications of the new generation technology and its impact on satellite earth station equipment can be identified and I hope to provide some insight into the wide range of satellite-based solutions and possibilities.

Following is a series of profiles depicting the application of new digital earth station technology. While these profiles are certainly not all-inclusive, they do represent communications requirements we frequently encounter.

Each profile identifies the basic characteristics of a particular area within a country, followed by typical communications requirements and finally, a description of current earth station technology to best meet those requirements. (see figures 1 - 4)

FIGURE 1

Application Profile: VSAT Earth Station

Site Characteristics

Location Type:

- Remote Industrial Site (Oil/Mining/Manufacturing)
- Corporate Branch Office
- Tourist Site
- Border Checkpoint

Communications Considerations

Communications Required:

- Primary Application: Interactive Data
- Batch Data
- 1-2 Channels Voice
- Video (receive only)

Traffic:

- Volume: Low Rate, Thin Route
- Channel Requirement: Low
- Erlang Loading: Low
- Network Connectivity: Star

Earth Station System

Earth Station Description:

- VSAT (Very Small Aperture Terminal)
- Thin-route, interactive data/voice between larger hub earth station and any number of remote, small aperture terminals
- Voice Compression: 9.6 - 16 KBPS
- Transmission Rate: 64/128 KBPS
- Modulation: BPSK
- Access Method: TDM and Slotted Aloha/TDMA
- Hub Station: 6-11 meter
- Remote Station: 1.8 - 3.6 meter

FIGURE 2

Application Profile: MCPC Earth Station

Site Characteristics

Location Type:

- Small-Medium Towns (Population 500 - 100,000)
- Remote Industrial Site (Oil/Mining/Manufacturing)

Communications Considerations

Communications Required:

- Multiple Voice Channels
- Data (low to medium rate)
- Video (receive only)
- Predictable communications requirements
- Traffic may increase over time

Traffic:

- Volume: Thin - Medium Route
- Channel Requirement: Low - Medium
- Erlang Loading: High
- Network Connectivity:
  - Point-to-Point
  - Point-to-Multipoint
  - Partial Mesh

Earth Station System

Earth Station Description:

- MCPC (Multi Channel Per Carrier)
- Small to medium aperture antenna with integrated RF terminal. Central hub with digital multiplexer and network control.
- Channels: 32 - 512 KBPS
- Modulation: BPSK/QPSK
- Access Method: Pre-Assigned
- Hub Station: 4.5 - 7.0 meter
- Remote Station: 1.8 - 4.5 meter

FIGURE 3

Application Profile: Digital DAMA Earth Station

Site Characteristics

Location Type:

- Small-Medium City
- (Population 2,500 - 150,000)

Communications Considerations

Communications Required:

- Voice (primary requirement)
- Occasional Data Traffic
- Shifting Traffic; variable routing required

Traffic:

- Volume: Medium Route
- Channel Requirement: Medium
- Erlang Loading: .1 to .8 / Trunk
- Network Connectivity:
  - Full Mesh

Earth System Station

Earth Station Description

- Digital DAMA (Demand-Assigned Multiple-Access)
- Small to medium aperture antenna with compact RF terminal. Central network hub with digital DAMA controller/network control.
- Voice Compression: 9.6 - 16 KBPS
- Channels: 1 - 60 per station, 16 KBPS each channel
- Modulation: QPSK
- Access Method: Demand Assigned
- Hub Station: 4.5 - 9.0 meter
- Remote Station: 1.8 - 3.6 meter

FIGURE 4

Application Profile: IBS/SMS Earth Station

Site Characteristics

Location Type:

- Medium-Large City
- (Population 10,000 - 1,000,000)
- Industrial Hub
- Teleport
- Heavy Commerce
- Smaller Industrial Hub with urgent communications requirements

Communications Considerations

Communications Required:

- Voice (single to multiple channels)
- Data (low to medium rate)
- Video (occasional or full-time)

Traffic:

- Volume: Medium Route, Medium Rate
- Channel Requirement: Medium
- Erlang Loading: High
- Network Connectivity:
  - Point-to-Point
  - Point-to-Multipoint

Earth System Station

Earth Station Description:

- IBS/SMS Digital System
- Small to large (Standard B, E and F) aperture antenna with compact RF terminal. Can operate with or without central network hub.
- Voice Compression: CCITT 32 KBPS (9.6 - 16 KBPS)
- Channels: 1 - 60 per station (64 - 2.048 KBPS)
- Modulation: QPSK
- Access Method: TDM/FDMA
- Hub Station: 6.0 - 11.0 meter (if required)
- Remote Station: 1.8 - 4.5 meter

ECONOMICS OF NEW-GENERATION DIGITAL EARTH STATIONS

With these application profiles, we have hopefully presented a new perspective on the application of current satellite technology, its influence on the design of satellite earth station products, and its ability to meet wide-ranging needs/applications.

However, technology improvements alone do not answer the economic challenges faced by telecommunication administrations today. As satellite equipment manufacturers and suppliers, we must provide not just the technical solution, but also the most cost effective solution.

New digital technology has powerful new capabilities, but the greater contribution is its impact on reducing cost and making satellite communication economically viable to a greater number of users.

The growing acceptance of satellite communications as a viable solution has given equipment manufacturers/suppliers the financial incentive for increased research and development. The resulting new developments, in turn, have produced even more effective solutions, and the cycle continues.

The result of these combined factors is a dramatic reduction in the cost of earth station technology. As an example, five years ago, an earth station to support one to five voice channels, using the analog SCPC technology, would have cost approximately $100,000. Today, a digital earth station with comparable capabilities costs in the range of $10,000 to $40,000.

Perhaps the most dramatic example is the application of a DAMA digital earth station. Five years ago, the cost of a DAMA earth station, supporting one to five voice channels was approximately $150,000. Today, with the advent of digital technology advances, that cost averages $50,000.

Plotted over the last five years, a look at this declining trend in earth station costs provides a backdrop for our brief overview of earth station economics. (see figure 5)

Administrations face a complex task of planning and justifying telecommunications investment, and the declining costs of earth stations have prompted a growing number of administrations to evaluate satellite technology. Evaluation is rarely based on price alone, but is certainly one of the first and most important planning elements. Earth station costs will vary of course, depending upon the application, but budgetary pricing is readily available.

With the many factors which play into technology cost, can administrations afford satellite communications? Is it within the reach of those trying to support remote areas?

To give telecommunications planners some perspective, I would like to present some current price ranges. (See figure 6.)

What is the impact of space segment on cost and economics?

The most fundamental elements are the source of satellite transmission and services selected. INTELSAT, for example, operates the largest number of telecommunication satellites and offers a wide range of services. In addition, regional and domestic/national satellites such as EUTELSAT, ARABSAT, ASIASAT, PALAPA, MORELOS, and others are presently being used by a great many countries with accessibility to these carriers.

Certainly, the availability of a domestic satellite, or the use of spot beams will dramatically alter the formula for space segment economics. Additionally, user requirements, such as international connectivity, will play a major role.

The following scenario presents a look at "typical" space segment costs based on the type of earth station used. The figures also include amortization of the earth station equipment. (See figure 7.)

Based on these monthly costs, a telephony channel can be provided for less than five cents per minute, including both earth station and satellite transponder costs. This analysis makes it clear that satellite telephony is no longer reserved strictly for administrations with large telecommunication budgets.

POTENTIAL FOR REVENUE-GENERATION AND PROFITABILITY

Clearly, the greatest justification for expanded telecommunications is the potential to provide and operate services at a profit. Not surprisingly, remote/rural areas tend to be the last to obtain services because of the perceived high cost to provide services. Until recently, governments thought of satellite communications in rather limited terms of national integration, information dissemination, or communication to/from other countries — in many ways like a public service.

New studies by the ITU and others show that investments in telecommunications increase domestic and foreign trade and offer an overwhelmingly favourable cost-to-benefit relationship. Properly planned and operated systems actually create revenue because it has been shown that users are willing to pay for the services they receive.

Also proven is the nearly immediate impact of telecommunications investment on improved economics and quality of life for areas which are presently underserved. Just one operating telephone within a day's walk of each rural village could have untold benefits, as described below:

- A World Bank survey, for example, reports that the installation of phones in several Asian villages allowed farmers to better coordinate sales of their products — they were able to increase their margins by 30 per cent.

- Another study by the ITU in Tonga showed the potential for similar increases in export prices, as well as decreases in import prices.

- Studies conducted by Dr. Charles Jonscher (Massachusetts Institute of Technology, United States) in Kenya, the Philippines, and Costa Rica indicate that the quantifiable benefits of introducing telephones outweighs cost by a factor of at least 5 to 1.

History shows that the improvement in local economies, more often than not, offsets initial telecommunications investment. From there, the cycle becomes self-supporting. Growing economies require additional telecommunication services which return more revenue to the administration. Success can be achieved with a well-planned and implemented telecommunications system. Even isolated populations can quickly participate as productive partners.

Initial investment is clearly a major issue. What is the cost to provide these services? For satellite communications, the advancements are lowering the cost of entry for many. New satellite technology, for example, allows users to add channel capacity and expand their systems incrementally. As a result, technology investment is commensurate with the potential for additional revenue.

All of these factors combine to present a dramatically improved economic picture for the telecommunications administrations.

More than 30 years have passed since the launch of ECHO-1, the first civilian communications satellite. ECHO-1 was an aluminum-coated plastic balloon, measuring 100 feet in diameter and weighing 168 pounds. Without reamplification, radio signals were simply bounced from its reflective surface.

Since the launch of ECHO-1, we have seen dramatic changes in satellite communications equipment and applications. For those who utilize this technology, this unprecedented change has been overwhelmingly positive. The steep decline in cost accompanied by the sharp increase in performance and benefits has sealed the role of satellite communications for rural and remote areas of the world.

Today, satellite communications hold out the promise of affordable communications for the many, not just the few. Telephony channels with costs of less than five cents per minute is a reality.

A New World Order is emerging, and with it, an increasing spirit of cooperativeness between nations. The growing desire to serve, not just the local, but rather the global markets has created opportunities which benefit millions.

Our ability to provide telecommunications services to rural and remote areas has never been greater but we must rise to meet the opportunity.

FIGURE 5

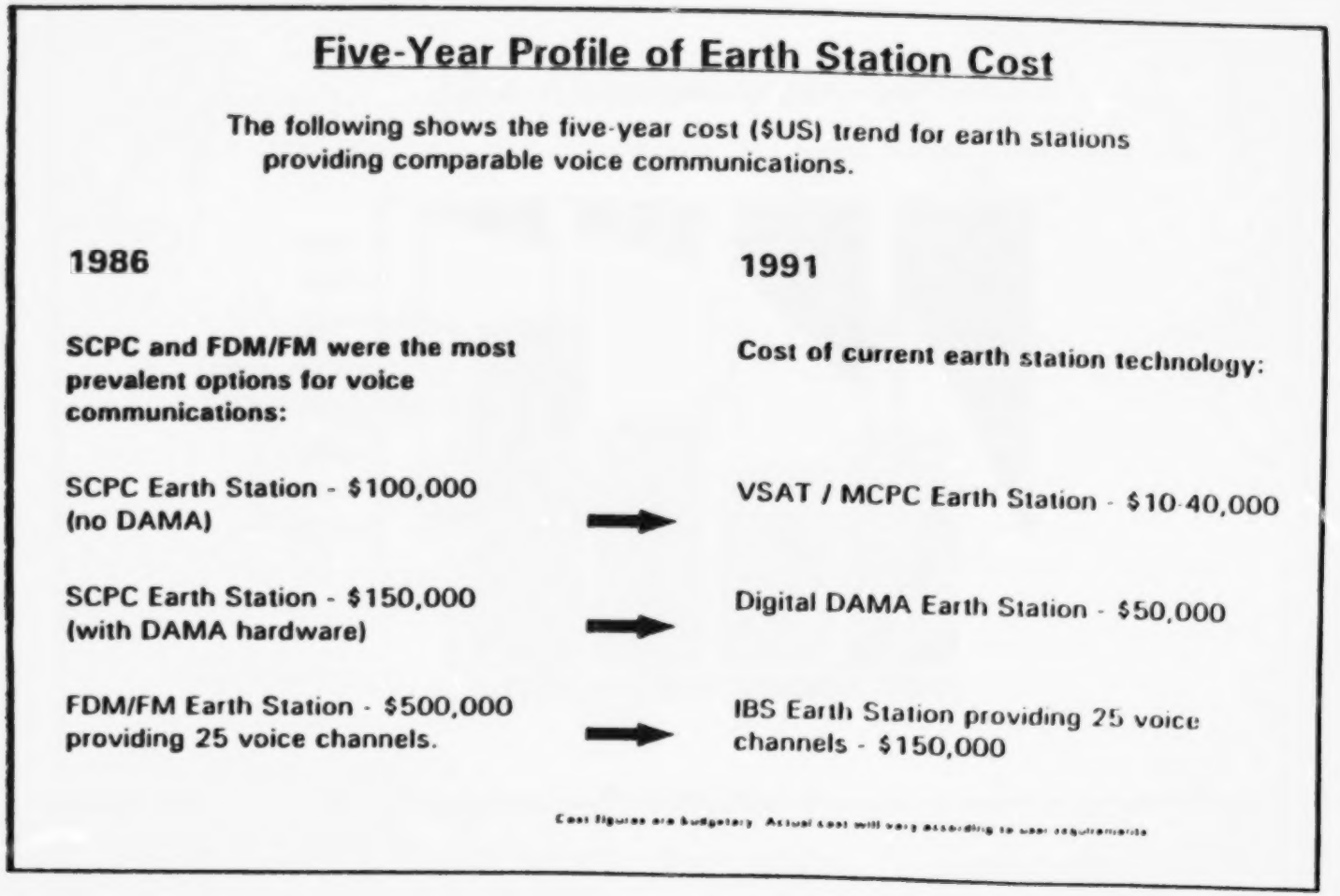

Five-Year Profile of Earth Station Cost
The following shows the five-year cost ($US) trend for earth stations providing comparable voice communications.
1986
1991
SCPC and FDM/FM were the most prevalent options for voice communications:
Cost of current earth station technology:
SCPC Earth Station - $100,000 (no DAMA)
VSAT / MCPC Earth Station - $10-40,000
SCPC Earth Station - $150,000 (with DAMA hardware)
Digital DAMA Earth Station - $50,000
FDM/FM Earth Station - $500,000 providing 25 voice channels.
IBS Earth Station providing 25 voice channels - $150,000
Cost figures are budgetary. Actual cost will vary according to user requirements

FIGURE 6

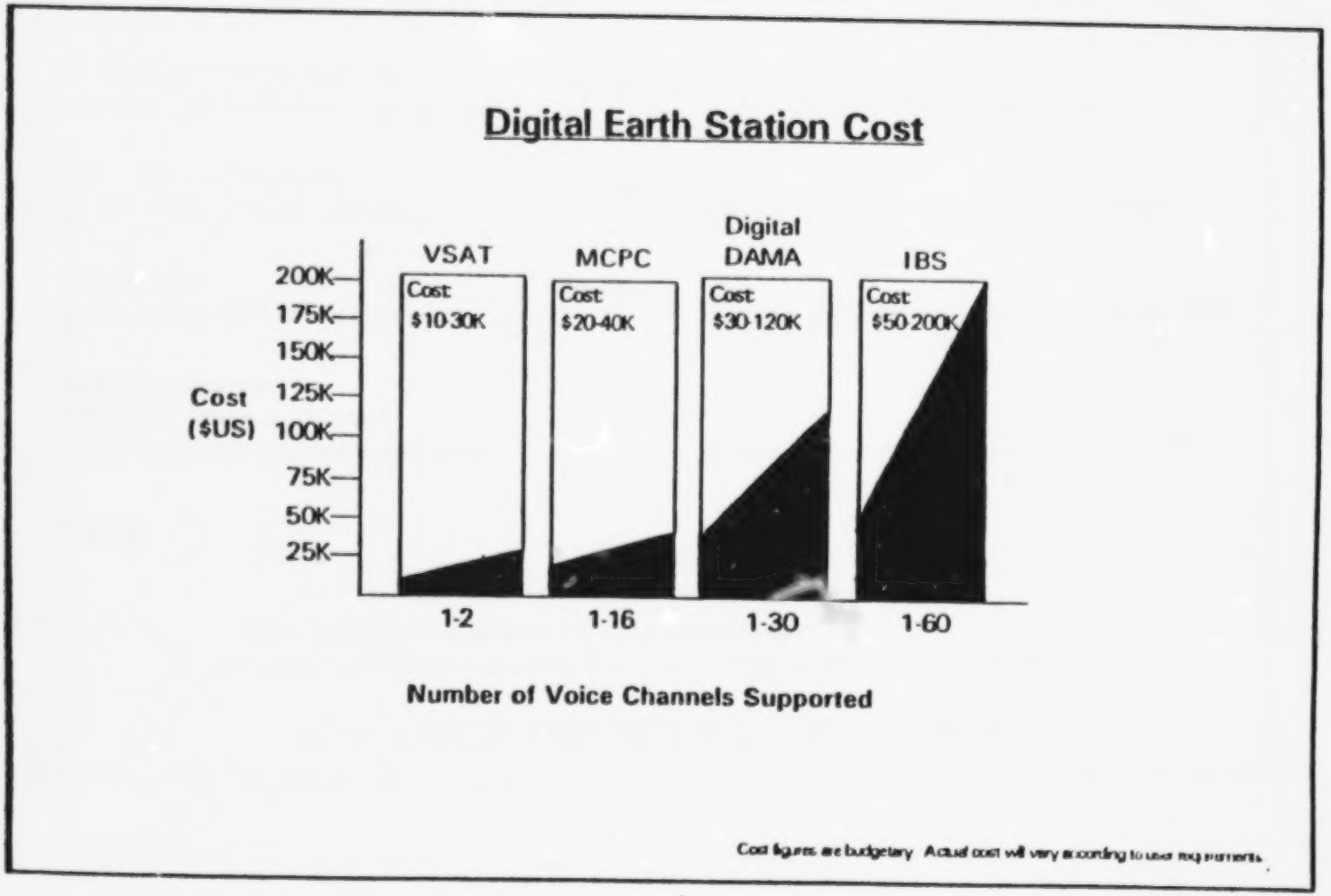
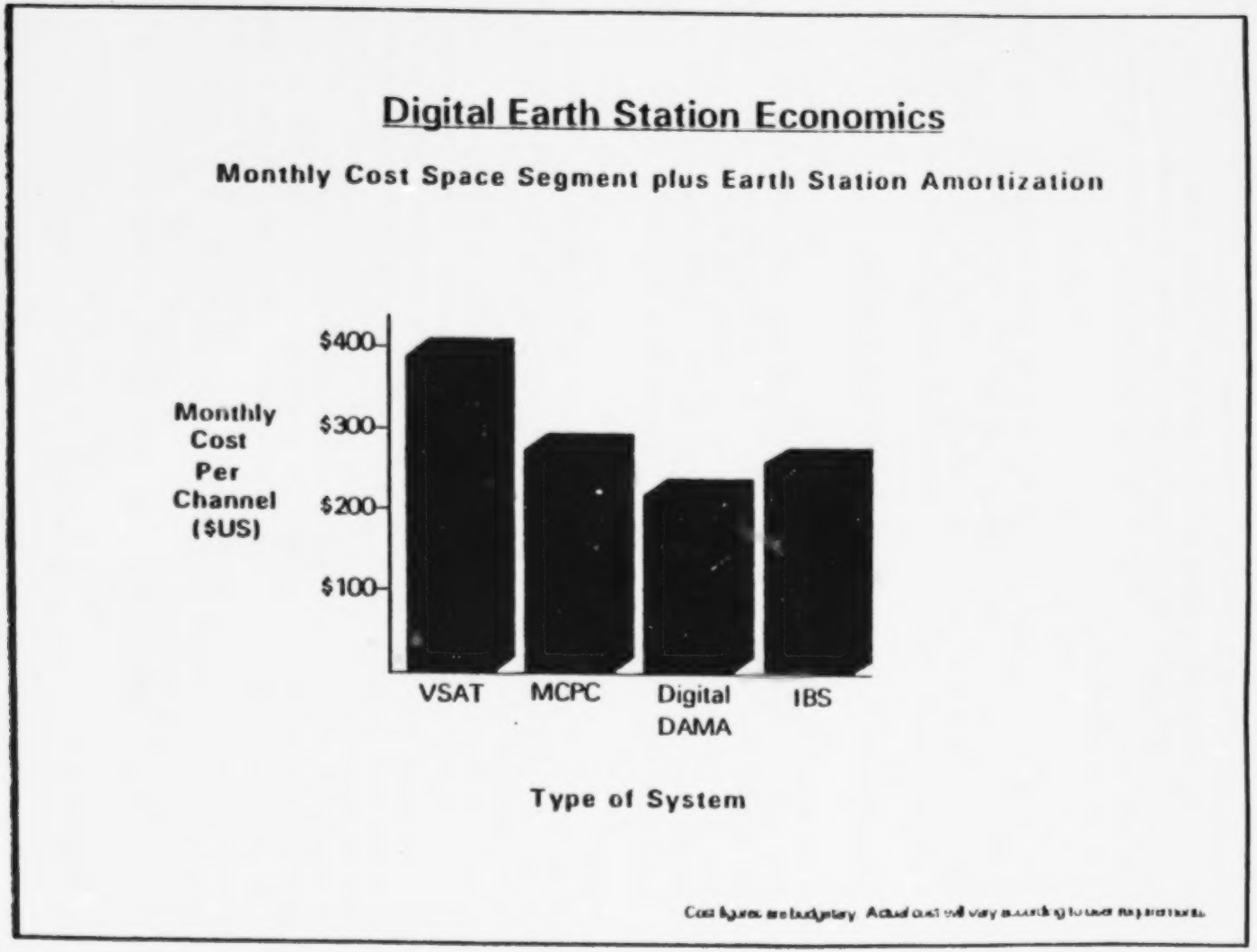

Digital Earth Station Cost
VSAT
MCPC
Digital DAMA
IBS
Cost ($US)
200K
175K
150K
125K
100K
75K
50K
25K
Cost $10-30K
Cost $20-40K
Cost $30-120K
Cost $50-200K
1-2
1-16
1-30
1-60
Number of Voice Channels Supported
Cost figures are budgetary. Actual cost will vary according to user requirements.

FIGURE 7


Digital Earth Station Economics
Monthly Cost Space Segment plus Earth Station Amortization
Monthly Cost Per Channel ($US)
$400
$300
$200
$100
VSAT
MCPC
Digital DAMA
IBS
Type of System
Cost figures are budgetary. Actual cost will vary according to user requirements.

SATCOM FOR EDUCATION AND RURAL DEVELOPMENT*

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INTRODUCTION

In the early stages of its development, satellite communication was constrained by the limitations of satellite technology. Low on-board power and inadequate station-keeping — among other things — required large antennas (with tracking capability) on the ground and expensive electronics. This limited applications to point-to-point use: trans-continental TV and telecommunication between a few locations having high traffic. While this provided specific benefits, there was little or no direct gain to rural areas. The advent of high-power satellites radically altered this scenario. New generation spacecraft with greater on-board power, large antennas, better station-keeping and electronics, made it possible to drastically reduce the size, complexity and cost of the ground facilities, especially for reception. Large-scale production led to economies of scale, and new technologies as well as new communication techniques contributed to further reductions in costs. Direct broadcast satellites made it feasible to receive, at a comparatively low-cost, TV programmes anywhere within the "footprint" of the satellite's transmission. This opened up immense possibilities in terms of TV transmission to rural and unserved areas, with the consequent potential of using this to spur development and education.

At the same time, it became possible to produce small and low-cost ground stations for telecommunications via satellite, so that underdeveloped and remote areas could be brought into the communications network. Subsequent developments in satellite and ground hardware technologies, as well as in communication techniques, have not only served to further accelerate these positive developments, but have also prompted new applications in the area of interactive and mobile communications.

SATELLITE INSTRUCTIONAL TELEVISION EXPERIMENT

The Satellite Instructional Television Experiment (SITE), conducted jointly by India and the United States in 1975-76, is a major milestone in the application of space technology.1/ Arthur Clarke called it "the greatest communication experiment in history" — for both its size as well as its innovative use of the most advanced

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* This paper, which was presented at the United Nations Workshop on Space Communications for Development, held in Seoul, Republic of Korea, 24- 27 November 1992, does not necessarily reflect the views of the United Nations.

technologies to tackle the problems of development in some of the least developed and poorest parts of India. SITE used the United States ATS-6 satellite to broadcast TV programmes for one year to about 2,400 villages in remote and backward regions of India. In each village, a "community" TV set was installed in a school or other suitable public place, so as to provide access to all residents of the village. Programmes broadcast from earth stations (in Ahmedabad and Delhi) via ATS-6 were received on these TV sets through a "direct reception system" consisting of a 3 m parabolic antenna and associated electronics. Some of these direct reception systems (about 150) were installed in villages which did not even have electric power. In these places, automobile batteries were used to power the sets. In a few villages, solar power was used to recharge the batteries, while in others, the batteries were periodically replaced. An elaborate maintenance system ensured minimum down-time of the sets. The programmes aimed at development, and covered agriculture, health, nutrition, family planning, etc. A substantial amount of time was devoted to educational programmes for children between the ages of 5 and 12 years.

A very extensive and detailed research effort was mounted to assess the impact of SITE, though it was clear that a mere one year experiment may not produce much by way of measurable changes. The major research findings from the numerous studies may be summarised as follows:

(a) It is possible to deploy, operate and maintain community TV sets and DBS even in remote areas of a country, with an availability of 80 per cent to 90 per cent;

(b) Community viewing is possible, and that average audience sizes of 80-100 can be expected;

(c) Instructional programmes were preferred, in comparison to pure entertainment programmes;

(d) Substantial gains were possible in the areas of health, hygiene and nutrition. The most dramatic gains were registered by female viewers, particularly illiterates;

(e) Despite case studies of innovations adopted in agriculture as a result of TV programmes, a large-scale survey did not show statistically significant gains; and

(f) Community access to TV tends to narrow the communications-effects gap.2/

THE INSAT SYSTEM AND EDUCATION

SITE was conceived as a precursor to an operational, nationwide domestic satellite system, for which detailed studies and planning had been initiated by India in the late-1960's.3/ The success of SITE provided an added impetus to these plans, and the domestic INSAT system became operational in 1982 with the launch of INSAT-IA. In the interim, between SITE and the launch of INSAT-IA, India conducted a series of experiments in the areas of telecommunications, TV distribution, digital communication, etc., first using the Franco-German Symphonie satellite and later the indigenously-made APPLE spacecraft. These helped to develop the expertise, hardware and techniques that would prove useful for the INSAT system.

The INSAT System presently consists of INSAT-ID (the fourth satellite of the INSAT-1 series, made abroad) and the indigenously designed and fabricated INSAT-2A.4/ The communication payload in the former includes 12 C-band and 2 high-power S band transponders; the INSAT 2A has 18 C-band (including the "extended" C band) and 2 high power S band transponders. The TV utilisation includes a substantial extent of use for educational purposes:

(a) Programmes for primary school children (5-12 years) with the objective of enriching their formal learning. These broadcasts are in five languages, for 45 minutes each, on five days of the week;

(b) Programmes for primary school teachers, once a week;

(c) Enrichment programmes at the undergraduate level for university students and others. These are presently only in one language (English), for two hours, six days each week;

(d) Distance learning programmes, broadcast for 30 minutes, three days a week; and

(e) Occasional programmes for literacy and adult education, as well as general education programmes broadcast from time to time.

The programmes for school children and teachers are broadcast in the morning, from 9 a.m. The distribution is via satellite for rebroadcast by the TV transmitters in the respective language region. Thus, the 45 minute transmission in each of five languages is rebroadcast by the TV transmitters located in that particular language zone, for reception in schools. Programmes are produced in Delhi and in six other studios located in the States whose languages are being broadcast.

The enrichment programmes for undergraduate students are broadcast in a single language (English) but production is done in 15 different centres established by the

University Grants Commission and located in various parts of the country. These are put together into integrated one-hour "capsules" and uplinked to the satellite from Delhi. The satellite signal is received and retransmitted by all the TV transmitters in the country. The programme — called Countrywide Classroom — is viewed in colleges as well as in homes.5/

The distance education programmes are produced by the Indira Gandhi National Open University and are specifically intended for students registered for various courses at the University. The programmes are uplinked to the satellite from Delhi and broadcast by the full network for 30 minutes on three days of each week. They are primarily in English.

A few other educational programmes, including those for literacy and adult education, are broadcast in the general transmission. There is little data that is recent, reliable and generalisable about audience sizes for these different programmes. However, the Countrywide Classroom and IGNOU programmes, because of their level as well as the language, will necessarily have a somewhat restricted audience. In all cases, the extent of viewing in the educational institutions is not very high, because of a variety of problems.

The INSAT system provides an excellent means of reaching rural areas, either through the extensive TV transmitter network, or by direct reception from satellite. The latter is now possible with parabolic ("dish") antenna of less than 1.5 m diameter, and for a cost equivalent to about $300. In an increasing number of areas, also including some villages, cable systems have been established, further reducing the cost to the viewer. Such "direct reception" is taking place of both, the S band (high power, BSS) channels as well as the C band (lower power, FSS) channels from INSAT. Though the high-power S band channels should in theory be far cheaper to receive, international demand and supply for satellite reception equipment is so much greater in C band that the cost of a reception system in this band is now almost the same, despite the lower power (EIRP) of this transmission compared to S band.

Despite the dramatic fall in prices of satellite reception equipment (partly due to advances in technology, and partly because of changes in import policies and tariffs in India), there are unfortunately only a very limited number of direct reception systems in rural areas. This is equally true for individual, private reception or for reception in educational institutions or in public places. Further, cable as a means of disseminating satellite-delivered programmes is only now making headway, and that too is primarily in the cities and big towns. While the growth rate of cable connections is phenomenal (as much as 40 per cent per year), it seems that dissemination of educational programmes, especially in rural areas, is going to be a continuing problem.

SATELLITE-BASED INTERACTIVE LEARNING

While the technologies for interactive communication systems have been commonplace for a while now, their actual use in India has been very limited. It was in this context that ISRO planned a series of application demonstrations, using the INSAT system.

The first of these, conducted for three days in February 1991, was a training course for trainers involved in adult education. The video programmes (both recorded and "live") were uplinked to the satellite from the ISRO earth station in Ahmedabad. These were received at two other sites, one in Ahmedabad itself and the other in a village, by means of a C band TVRO. The same terminal was augmented and modified to transmit back via satellite a voice channel to the originating earth station. This enabled participants from the two "remote" locations to ask questions and to interact with the teacher and other participants at the originating (or "teaching") end. A research study indicated that:

> "Compared to face-to-face instruction, this training was viewed by most trainees as a better and effective approach in covering a large and scattered group of trainees in a limited time."6/

Given the need and importance of the adult education programme in India, the significance of quicker and better (and standardised) training for the trainees scattered all over the vast country, is obvious. Therefore, if delivery of training programmes can be augmented with interaction to make learning more effective, then such a system is of crucial importance.

The "talk-back terminal" (enabling a return voice link via satellite, apart from reception of the TV signal) was put to more extensive use in a week-long experiment done jointly by ISRO and the University Grants Commission in November 1991. In this experiment the uplinking of the recorded TV programmes for undergraduate students was done from Delhi. These were received and rebroadcast by the full TV network as part of the usual Countrywide Classroom broadcasts. At eight specific locations, special arrangements were made for interaction: at two via satellite (using the talk-back terminal), and at the other six by the normal Public Switched Telephone Network. The system was configured so that the questions from any location (and, of course, the replies from the teaching/originating point in Delhi) were looped back into the broadcast and hence audible to all viewers. Thus, while questions could only be asked by the students in the eight pre-determined locations, all viewers could hear the questions and hear/see the replies. Such vicarious participation will, it is hoped, increase viewers' interest and attention and hence learning. Research studies, however, were not conclusive about the benefits though a number of improvements were suggested (e.g. more time for the interaction). This may be due to the design of the experiment and selection of programmes (there was no coherent "learning package", with a great

diversity of programme content; also, each group of students was exposed only for two days). Further experimentation is planned to study the pedagogic benefits.

Similar experiments were conducted, though without the broadcast component (i.e. restricted to a few centres receiving the programmes directly from satellite), for continuing education in industry (for supervisory staff) at eight locations; for training of development functionaries in rural areas, with four receiving centres; and for part-time students of engineering. In each case, the one-way-video, two-way-audio mode was used to provide learning material through TV, and to follow this with an interactive session. Research findings indicate a very favourable response. However, it is also clear that some changes and improvements are necessary in order to be more effective.7/ Also, costs and economic viability have to be taken into account if an on-going operational system is to be established.

The "talk-back terminal" with TV reception capability and voice-transmit capability (both via satellite, both in C band) needs to be low-cost, easy to operate and capable of providing high quality channels. The "teaching end" needs simple aids like a voice-mail system for storing questions and/or a delay line to screen in-coming calls before they are re-broadcast. Also desirable are some teaching aids like an electronic blackboard, a Video Typewriter, quick-access video etc. In order to provide access to all viewers (for programmes that go out in the broadcast mode, as opposed to those that are restricted to a closed group). A system of "toll free numbers" is also necessary so that a person can ask a question from any telephone in the country.

Experiments that take account of these suggestions are now being planned. They will also include computer and facsimile linkages between the "receiving end" (classroom) and the originating/teaching end. The desirability of a return video — by still-picture or slow-scan — will also be examined. The touchstone of success for all these will have to be the extent to which learning is improved or accelerated, and not the more smooth functioning of the hardware.

OTHER APPLICATIONS OF SATCOM

While TV is the most visible and most glamorous application of satellite communications, there are a number of other technologies and systems that also have the potential to contribute greatly to rural development. This paper does not intend to cover these in any great depth. However, mention must be made of the following, in respect to India:

(a) Satellite-based Rural Telegraphy Network : Telegraphy is a service of vital importance to the "common man" in India, especially in rural areas. Though used only occasionally, it is the vital — and only — means for families to convey urgent messages to relatives located elsewhere or vice versa (e.g. to and from the growing numbers of migrants who take up jobs

in cities or on farms far away). Telephones are ruled out due to lack of access at both ends, and high costs. Also, in the case of almost all urgent messages, one-way communication is adequate. For this, the comparatively low cost and "home delivery" make telegrams the preferred mode. The present telegraph system, based on obsolete technology, causes long delays and errors. The satellite-based system, using 2.5 m antennas and working in the TDM/TDMA mode in C band, will vastly improve the system and lower costs.8/ It is now proposed to use this for another vital application, money orders (i.e. funds transfers). This new system will make life a little better in the remote/rural areas and will contribute, albeit indirectly, to development.

(b) Disaster Warning System : A vital humanitarian service that uses the broadcast mode (one of the "radio networking" channels on a S band transponder) is the Disaster Warning System (DWS).9/ About 100 DWS terminals, established as an experiment in fishing villages on the cyclone-prone east coast of India, can be selectively addressed via satellite. A Cyclone Warning Centre sends out a signal via satellite, and this activates a siren in the DWS terminals in the specific locations threatened by an impending cyclone. Appropriate warning and action messages then follow, so that preventive measures (including evacuation) can be taken by the villagers. The DWS is expected to overcome the inadequacies and unreliability of the traditional system, and lead to a saving of life and property. The beneficiaries will be primarily the disadvantaged: fishermen and poor villagers whose life has been constantly disrupted by the regular but unpredictable havoc caused by nature.

(c) Rural Telephone: The establishment of small rural telephone exchanges and the linking of these into the network via satellite has had a substantial economic effect in certain rural areas. Case studies from three areas of the country covering three different fields (fruit, fish and poultry) point to the economic gains from better communication made possible by Satcom.10/ It is true that the primary benefit in such cases goes to the traders and organized business. However, this does translate to somewhat better prices for the producers, and general economic development of the area. The satellite, in this case, provides an instant and high-quality link to the market (including, in the case of fisheries, to international buyers), enabling the realization of higher prices and optimal despatches.

(d) Information Networks: A major satellite-based network has been established by the National Information Centre (NIC). This will link all the district headquarters (about 500) to the State capitals and to Delhi for creating and accessing data bases. Ultimately, the system may be expanded to cover 5,000 locations. The availability of up-to-date data on

an instantaneous basis will, it is hoped, make for better decision-making. Initially, the major users are likely to be in Delhi or the State capitals. However, increasingly the system could, for example, be used by the district administration to draw-up, continuously monitor and modify decentralized plans for the district, or to monitor projects. This should make a vital contribution to development. Equally important, access to information at the local level should enable villagers to participate in the development process.

Other networks are also being established for a variety of specialized purposes. One of these, INFLIBNET, is an information and library network in the education sector, for universities. This will help teachers, students and researchers located in any university in India to access the latest research findings or to get data from data banks, or to interact with each other. This will be of particular value to students and teachers located in the rural or more remote areas, since they will be able to get the latest information through this network.

Apart from these, other newer possibilities are also being opened up by satellite communications technology. Mobile communication and RDSS, for example, could be of use in rural areas for messages to and from trucks, remote construction sites of dams, power houses, roads, etc. Since these are inevitably in rural areas, they have a special contribution to make towards rural development. Telemedicine is another application with great potential. While some experiments have been successfully conducted (including in Canada, the United States as well as in India), costs and complexity preclude operationalisation, except possibly in very special situations.

ADVANTAGES AND LIMITATIONS OF SATCOM

The Indian experience indicates both advantages/benefits as well as certain limitations to the use of satellite communications for rural education and development. Among the advantages are:

(a) Wide reach, basically unconstrained by terrain (in contrast to "shadow areas" in the coverage of a conventional TV transmitters), and capability to reach even the most remote areas;

(b) No dependence on intermediate infrastructure, since the satellite is able to directly access to (and from) any location. This also helps to minimize noise and distortion (natural, equipment generated, as well as man-made);

(c) Reliability of operations, especially in contrast to existing infrastructure in the rural areas;

(d) Lower cost per beneficiary, compared to conventional systems, especially in rural areas;

(e) Extensive area-coverage, making it ideal for applications where the beneficiaries, though large in number, are scattered over a large area (e.g., professionals like doctors/engineers or students of a National Open University); and

(f) Quicker implementation; flexibility, very short lead-times and lower costs for adding new locations once the systems is established.

Experience has also indicated certain limitations in the use of satellite communications for rural development and education in the Indian context. The limitations include the following factors:

(a) Any broadcast for rural areas requires the use of the local language. Thus, some "regionalization" of coverage is essential. This is, of course, feasible and is being done, however, to the extent the area and potential audience size is reduced, resulting in a higher cost per beneficiary;

(b) Apart from language, development programmes (especially those that are action-oriented) require even narrower geographical focus. This often requires local broadcasting. In such a situation, a satellite channel is useful only to provide a "window to the world." Education, of course, does not require such narrow localisation;

(c) The high cost — by Indian standards — of direct (or even cable) reception of satellite broadcasts. Unfortunately, it is the more remote areas that are not covered by terrestrial TV transmitters, and therefore have to pay the "penalty" of the extra cost of a direct reception system. Of course, this provides them a service that they would not have otherwise got, possibly for many years;

(d) Problems of maintenance, availability and quality of electric supply, custody and operation of community-access sets, etc. These, of course, are features of any rural community TV set system, and are not peculiar to a satellite-based system; and

(e) Difficulty in getting quick and reliable feedback on programmes. Logistics and cultural factors make research in the rural areas more problematic.

CONCLUSION

The Indian experience in using satellite communications for rural development has been both extensive and in-depth. It has covered a wide variety of fields (agriculture, health, primary and undergraduate level education, distance learning, training of workers, etc.), a number of technologies (TV, telecommunication, messaging, "talkback") and a large span of time (beginning in 1975). The previous section enumerated certain advantages and limitations of satellite communications, primarily in the context of the technology. Keeping these in mind, the essence of the Indian experience could be summarized in the following general conclusions:11/

(a) While community TV sets in villages are both feasible and desirable, their working is dependent upon the existence of a well-organized and efficient maintenance system in which personnel work with considerable dedication and motivation. The operation (i.e., switching on) of the set depends upon: (a) programme content; (b) the set "custodian" and (c) availability of power. Having a custodian from the particular village itself can be of great help, as is the use of battery-operated TV sets, not dependent on the often unreliable power supply from the mains.

(b) Equally challenging as the issue of set operation and maintenance is the activity related to installation of sets in remote rural areas. This vital task requires systematic planning, efficient execution and close monitoring. This activity includes selection of villages and the specific location in the villages for installation of sets, ensuring the availability of electricity in the selected building (except in the case of battery-operated sets) and actual installation. Careful and detailed planning with regard to the number of teams, transportation requirements, optimal procedures for installation, test and check out, etc., is essential for the timely completion of the deployment operations. Without this, it is doubtful if any time-bound deployment of equipment in remote rural areas can be successfully accomplished.

(c) TV sets located in small towns or cities face a slightly less hostile environment. Even so, the problems of set maintenance, of operation, of a "custodian," etc., are similar to those of sets in villages.

(d) For certain types of programmes, the need and importance of infrastructure support is obvious. Thus, an agriculture programme promoting a new variety of seeds is meaningful only if the seed can be made available to the farmer. Similarly, a programme recommending vaccination requires that vaccination facilities be available in the villages concerned. Coordination between extension agencies/field-workers and the programme-makers is therefore essential. Since the infrastructure will vary from place to place as will the availability of physical inputs (seeds,

vaccines, etc.), the need for "localisation" in such developmental programmes becomes at once obvious.

(e) Viewing of programmes in institutional settings (schools, colleges, factories) is ideal, because the teacher/"animateur" can lead a discussion after the programme. However, this is feasible only if viewing can be built into the work-day schedule and be well organized. Also, print-support material (including broadcast schedules) should be available at each location in time (especially for distance learning).

(f) A project that involves the close working together of a number of government Ministries/Departments, agencies, etc., including State (local) governments, requires a well-structured organization and an efficient management system. The need to mesh together and integrate diverse activities implies good coordination and an effective monitoring system. The importance of the total managerial function, and especially of the system management role, is a vital lesson of the Indian experience.

(g) Within the managerial system, while advance planning is a necessary element in a project involving long gestation activities (especially including hardware development), an equally essential element is the anticipation of potential problems, flexibility and the preparation of contingency or work-around plans. Such "planning-for-obstacles" is particularly useful in the high-uncertainty situation inherent in any path-breaking project involving altogether new activities. Equally important is a quick response-time in reaction to unforeseen situations.

(h) Programme-production is often undertaken on a crash basis because this activity does not start soon enough. As a result, programme content and quality leave much to be desired. Similarly, the communications research component inevitably becomes operational far too late, if at all. Ideally these activities must begin well before the start of broadcasts: at least three years in advance for research and two years for programme production. Availability of personnel and their training, if necessary, must be completed before this period.

(i) Overall, it can be said that the extension of communications infrastructure to remote areas is not only feasible, but that it can contribute concretely to promoting national development. Satellite communications is a major and quick way of doing this, especially in developing countries with poor existing communication infrastructure.

These general conclusions, based on the experience in India, may be useful to other developing countries, in the planning and execution of their system.

It is also necessary to note that the benefits flowing from satellite communications systems are not uniformly available to all.12/ Special planning of systems and of intervention is essential if the gains are to go to those with the greatest need: the rural disadvantaged.

It would, however, be worthwhile to finally take note of one major point. While the basic technologies are common, the system configuration must be need-based and therefore specific to the situation and context of each country. As such, there can be no single "formula". Yet there would be similarities, especially in the process of planning and implementation as well as in the concerns and pitfalls, and others could certainly benefit from and build on the experience in India.

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POTENTIALS AND CONSTRAINTS OF APPLYING REMOTE SENSING TECHNOLOGY FOR AGRICULTURAL RESOURCE MANAGEMENT IN NIGERIA*

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INTRODUCTION

One of the fundamental problems facing most African countries today, especially Nigeria, is the co-existence of "abundant natural resources" and widespread poverty, characterized by inadequate provision of food, shelter, potable water, health facilities and opportunities for employment. This situation presents a fundamental problem and a deep-rooted drag on resource management. As noted by the World Commission on Environment and Development (1987), "Those who are poor and hungry will often destroy their immediate environment in order to survive: They will cut down forests, their livestock will overgraze grasslands; They will over use marginal lands and in growing numbers they will crowd into congested cities"1/. All these and more have continued to occur in Nigeria. Agriculture, on which over 70 per cent of the population depends, has also failed to:

(i) Contribute savings most needed for overall national development;

(ii) Supply food and industrial material;

(iii) Support local purchasing power for manufactured goods; and

(iv) Provide employment and security.

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This situation is not unrecognized. For example, the Organization for African Unity (OAU) declared in its report on the Lagos plan of Action for Economic Development of Africa that:

> "The major problems confronting Africa in the field of natural resources development include: lack of information on natural resources endowment and the activities of transnational corporations dealing with natural resource assessment; lack of adequate capacity (capital, skill and technology) for the development of these resources; a considerable dependence on foreign transnational corporations for the development of a narrow range of African natural resources selected by these corporations to supply new material needs of the developed countries...and disappointingly low general contribution of natural resources to socio-economic development."2/

In view of the worsening economic situation six years after this continental acknowledgement of poor natural resources information and the unacceptable contribution of natural resources, especially agriculture, to the socio-economic development of the continent, African Heads of States and Governments further declared, in their report on the African Priority Programme for Economic Recovery, 1986-1990 that:

> "We recognize that effective mobilisation and judicious exploitation of our national and collective potentials on the basis of well-formulated development strategies and plans are vital to the eradication of famine and the control of drought and desertification and for the rehabilitation of agriculture in Africa."3/

In spite of these declarations, agricultural production continues to decline while the resource base is shrinking. This does not mean that programmes have not been initiated but rather that the critical issue of resource information needed to assist in the planning, management and development of the resources has largely remained a rhetorical and residual matter.

Prior to the OAU declarations, the need for resource information in Africa and the potential of satellite remote sensing technology in meeting some of the needs were well known.4/

It was this knowledge that led to massive programmes on the transfer of the technology to developing countries by several international organizations and national agencies from the industrialized countries. While several developing countries, especially those in Asia and Latin America, have successfully adopted the technology and are applying it for their national needs, Nigeria has yet to take full advantage of the potential of this revolutionary technology. Set against this background, this paper examines the potential of remote sensing technology for agricultural resource

management and identifies the major constraints inhibiting its adoption and application. To do this, an overview of agricultural programmes is provided. These considerations form the basis for offering some suggestions on how the identified obstacles could be removed.

AN OVERVIEW OF AGRICULTURAL PROGRAMMES IN NIGERIA

Prior to colonial administration in Nigeria, agricultural practices were dominated by subsistence farming largely for food production. During the colonial period, agricultural programmes were largely focused on the exploitation of cash crops such as cocoa, oil palm, cotton and groundnut. Mixed farming, based on the Cambridge School of agriculture was introduced without adequate consideration of local agricultural practices. This was followed by the introduction of large-scale agricultural plantation schemes in response to developments in the use of machinery in Europe. A typical example was the Niger Agricultural Project in Mokuwa which replicated the disastrous experience of the East African groundnut scheme.5/ Several such agricultural plantations were established, but the programmes failed because no detailed investigation of soils, climate and marketing was done.

These programmes encouraged the rapid expansion of cash crop cultivation into forest and marginal areas. Because the need to focus on selected export crops had been created, production of food crops received little attention. Consequently, all of Nigeria's major export crop producing areas became "food-deficit areas" and they have remained so up to now.6/ However, with a population then under 50 million and high mortality rates, the environmental degradation effect of the programmes was inconsequential at the time.

After independence in 1960, agricultural policies have been, and continue to be characterized by the proliferation of programmes and institutions based on transferential strategies.7/ In spite of the failure of the agricultural plantations initiated during the colonial period, farm settlements based on the Israeli Moshavim system were developed in the western and eastern parts of Nigeria. Like its colonial predecessor, the scheme failed because it attempted to transfer a system from an environment with totally different historical experience and ideological commitment. More importantly, the scheme failed because of inadequate planning, poor administrative set-up, total lack of environmental and resource information and the inability to monitor and assess the socio-economic and ecological impact of the schemes.

The abundant oil discoveries in the 1960s and its increasing exploitation at the end of the civil war in 1970, brought about a shift in the organization of resource use and management systems in favour of reconstruction programmes and urban-based developments (see Table 1). This led to widespread loss of interest, not only in the production of export crops but also in the production of traditional food crops (Tables 2a and 2b). Although agriculture accounted for over 60 per cent of the Gross Domestic

Product (GDP) in 1960-61, over 66 per cent of the export value with about 95 per cent of food requirements provided locally by 1978, agricultural export and the contribution of agriculture to GDP had declined to 5 per cent and 19.8 per cent respectively while food imports increased to over 95 per cent.8/

In response to the collapsing agricultural systems in the country, several institutions, programmes and projects have been established. They include:

(i) Eleven River Basin Development Authorities;

(ii) Construction of dams/reservoirs for large scale irrigation projects;

(iii) Establishment of prestigious agricultural research institutes under the Federal Ministry of Science and Technology9/

(iv) Large-scale importance of chemical fertilizer and pesticides;

(v) Establishment of the National Centre for Agricultural Mechanisation and the Agricultural Bank;

(vi) Operation Feed the Nation programme that induced individuals to engage in any form of small-scale farming.

(vii) Promulgation of a land use decree in 1978;

(viii) Green revolution programme (1979-1983);

(ix) Establishment of the Directorate of Food, Roads and Rural Infrastructures (DEFRRI) in 1986.

(x) Establishment of two Federal Universities of Agriculture in 1988; and

(xi) Establishment of a National Agricultural Land Development Authority (NALDA) in 1991.

Several other agricultural related committees/agencies have also been established. They include: the National Committee for Land Resources Development (NCLRD); the National Livestock Development Committee (NLDC); the National Committee on Soil Conservation (NCSC); the National Committee on Ecological Problems (NCEP); the Natural Resources Conservation Council (NRCC) serviced by the National Committee on the conservation of Renewable Resources (NCCRR); the Federal Environment Protection Agency (FEPA); the National Committee on Drought and Desertification (NCDD) and the National Committee on Arid Zone Afforestation (NCAZA). The

members of these national committees are mostly drawn from the Federal Ministry of Agriculture, Water Resources and Rural Development.

In addition, there are five World Bank supported programmes.

(i) The Federal Agricultural Coordinating Unit (FACU) which provides technical support to the State-level Agricultural Development Projects (ADPs),

(ii) The National Agricultural Extension and Research Liaison Service (NAERLS);

(iii) The Agricultural Projects Monitoring and Evaluation Unit (APMEU);

(iv) The Afforestation Programme Coordinating Unit (APCU) and

(v) The Forest Management, Evaluation and Coordination Unit (FORMECU).

In spite of the programmes and several agencies/committees established to improve the agricultural sector of the Nigerian economy, the 1991 World Bank report indicated a general fall in the growth of production, a fall in the average growth of agriculture from 1.7 per cent to 1.3 per cent with the GDP dropping from 6.1 per cent to 0.4 per cent.10/

The persistently poor performance of agriculture is caused by several factors among which are the following:

(i) Most of the agricultural programmes have been based on a transferential (universal) development strategy, and they are carried out in a disjointed, incremental fashion that forecloses all other modes of development once the decision and "compelling commitments" have been made. They are also characterized by conflicting and ad-hoc goals with overlapping objectives.

(ii) The notion of "abundant natural resources" and the adoption of the transferential development strategy have led to an uncritical consideration and thorough understanding of the term "resource," the concept of "resource management" and the integration of ecological, economic, technological and ethnological approaches to agricultural resources management.

(iii) Resources are viewed sectorally; consequently, the policies adopted to deal with them are therefore incompatible with the factors that condition resource management. In effect, all the agencies are mostly preoccupied with sectoral and financial planning leading to dependence on external aid organizations and hybrid consultants to deal with resource management. The agencies themselves

remain passive while the "purported beneficiaries" of their programmes (the rural farmers) are isolated.

(iv) There is an absolute lack of coordination among agricultural agencies. A monodisciplinary approach is adopted even within the Federal Ministry of Agriculture, Water Resources and Rural Development. Similarly, there is a lack of coordination between agricultural agencies and other agencies dealing with other natural resource components. This situation had led to uncoordinated efforts between the "more influential economic planners/advisers" who are usually unaware of the need for spatial and thematic resource information and the resource planners/managers whose concern is the location, distribution, quantity and suitability of resources.

(v) Apart from the above weaknesses in agricultural resource management, the most important factor which has not been given any serious consideration is the near absolute lack of basic spatial and temporal resource information. As of today, Nigeria does not have national inventories of agricultural lands, crops, water resources (both surface and underground), and rangelands. Soil maps at 1:500,000 started years ago have not yet been published. There are no complete national topographic maps at 1:50,000. Those that are available are over 25 years old. Rural settlement and road maps are not available. Spatially detailed climatological data are a rarity. The available spatial resource data, mostly acquired through contracts for specific purposes are kept in files of the agencies and access to them remains a difficult task. The national utilization of the fragmentary data sources is further compounded by the lack of uniform national classification schemes and the use of various geographical referencing systems.

The incompleteness, obsolescence and inaccuracy of the available resource information often render them unsatisfactory as a base for development decisions.11/

The lack of basic resource inventories, which are largely taken for granted in industrialized countries, has greatly contributed to the failure of most agricultural programmes in Nigeria. Two examples illustrate this point: (a) In the last decade, several million dollars (US) have been spent on the importation of chemical fertilizers in order to improve the fertility of the soils. This programme has not been supported by soil inventories on which to base the national application of the fertilizers. Thus, the fertilizer is distributed to mostly illiterate farmers leading to its misapplication and unintentional negative impacts;12/ (b) In order to create an avenue for orderly development of urban and rural areas and to aid in the implementation of the various agricultural, housing and industrial programmes, a Land Use Decree (now Act) was promulgated in 1978. The main objective of the Act, as contained in its preamble, stated that: "...It is in the public interest that the rights of all Nigerians to the land of Nigeria be asserted and preserved by law (and that) it is also in the public interest that the rights of all Nigerians to use and enjoy land in Nigeria and the natural fruits thereof in

sufficient quantity to enable them to provide for the sustenance of themselves and their families should be assured, protected and preserved".

To execute the Act, land in the territory of each State is vested in the Governor of the State who holds the land in trust and administers it for the use and common benefit of all Nigerians.

Some of the envisaged benefits of the Act include: (i) stoppage of intra- and inter-family/community disputes over land; (ii) an end to uncontrolled conversion of rural, prime agricultural land to urban use; (iii) accessibility to agricultural land and consolidation of fragmented agricultural land; (iv) prevention of developments that are incompatible with the natural attributes of the land; and (v) assurance of proper land management.

In spite of the good intentions of the Land Use Act, the above objectives have not been met because there is no national, state and/or land use maps to show the existing situation and/or to be used for planning and monitoring purposes. A situation where a Governor does not know the size, location, quality, ownership and current use of the land vested in him for administration is totally at variance with the intentions of the Land Use Act.

The prestigious agricultural research institutes established for every major crop in Nigeria has not made any appreciable contribution to agricultural production and management. These elitist institutes do not know precisely where the crops are grown, the quality of the crops, their yields and the area planted to these crops. Agricultural training and research in many developing countries are conservative, and elitist and they often concentrate on topics such as crop genetics and hybridization, agricultural mechanisation for large-scale production systems, etc.13/

While the topics are not unimportant in themselves, they seem to be premature where such fundamental questions of location, quality, availability of agricultural land, effects of land tenure on agricultural production and spatial and temporal changes in crop demands have not been adequately addressed.

This has been the situation in Nigeria where well-articulated agricultural modernization proposals have failed to be implemented or have been poorly implemented because of inadequate knowledge of how the land is currently being utilized, the capability/suitability of the land, the local response to new measures being introduced and the ability to monitor the impact of such programmes.

From the foregoing, it is clear that agriculture in Nigeria has been subjected to various fashionable innovations with little or nothing to show for it. The only innovation which has not been particularly integrated into agricultural planning is resource information. The objectives of current agricultural policies include:

(i) attainment of self-sufficiency in basic food commodities;

(ii) increased production of agricultural raw material for industry;

(iii) increased production and processing of export crops;

(iv) modernization of agricultural production, processing, storage and distribution through improved technology;

(v) increased rural employment;

(vi) improvement of the quality of life of the rural population; and

(vii) improved protection of agricultural land

If these objectives are to be achieved and sustained, priority attention should be given to the application of remote sensing for the acquisition of fundamental resource information.

POTENTIAL OF REMOTE SENSING FOR AGRICULTURAL RESOURCE MANAGEMENT IN NIGERIA

Given the lack of most spatial and temporal agricultural resource information as well as the incompleteness, obsolescence and the inaccessibility of those that are available, satellite remote sensing has the greatest potential to provide needed resource information required for the successful implementation of the current Nigerian agricultural policy. The sheer magnitude of the information required, the tasks involved and the urgency, render conventional survey and data collection methods inadequate.

The potential of satellite remote sensing is dictated by its inherent characteristics such as its application flexibility; synoptic coverage of large areas in a consistent manner; its ability to monitor sequentially, periodically, and frequently physical and cultural changes in response to temporal requirements of planning activities, greater reliability and permanence of records. Remotely sensed data therefore provide information about the location, quantity, quality, areal extent as well as spatial and temporal relationships of objects. These are some of the characteristics:

(i) the development of different sensors, operating at different platforms within different regions of the EMS with more selective capability to detect variations in environmental conditions;

(ii) the increasing possibility of combining and enhancing multiple and multitemporal data sets through digital processing;

(iii) the increasing ability to integrate remotely sensed data with socio-economic data through the application of geographic information systems (GIS);

(iv) the development of knowledge-based expert systems have greatly increased the potential of remote sensing.

Broadly, the potential of remote sensing has been explored for the following purposes:

(i) Conducting resource inventories;

(ii) Detection of changes in the resources and the way they are being utilized;

(iii) Monitoring of dynamic resources or events (e.g. growth of vegetation or crops, sedimentation in rivers and lakes; natural disaster etc);

(iv) Forecasting;

(v) Managing of the resources.14/ All of these are essential for rational agricultural resources development and management programmes.

The potential of remote sensing technology for agricultural planning, development and management have been explored for a large number of purposes including:

(i) General land use inventory and mapping;

(ii) Inventory and mapping of rainfed agricultural lands; irrigated agricultural lands; flood plain agricultural land and agricultural fallow lands;

(iii) Inventory of tree cash crops;

(iv) Annual crop inventory and mapping;

(v) Soil categorization and mapping

(vi) Surface water inventory and groundwater targeting;

(vii) Flood area mapping;

(viii) Inventory of degraded lands

(ix) Land capability/suitability mapping;

(x) Rangelands inventory and mapping and range forage production and grazing capacity;

(xi) Farm planning and plot layout;

(xii) Detection of changes in agricultural land use pattern;

(xiii) Derivation of changes in agricultural land use pattern;

(xiv) Monitoring of crop conditions including weeds, herbicide and fertilizer misapplication;

(xv) Estimation of agroclimatological parameters (e.g. rainfall, temperature etc);

(xvi) Weather forecast to support agricultural activities;

(xvii) Early detection of crop and vegetation deceases, bush fires and mapping of their areal extent; and

(xviii) Preparation of regional maps showing in particular, the location of existing settlements and rural feeder roads.

This list is certainly not complete but through careful selection and combined use of the available sensors (e.g. Landsat (MSS & TM), SPOT [P, XS and P/XS], NOAA-AVHRR, etc.), based on dedicated local research and action-oriented projects, have been employed to acquire information on the listed areas.15/

In most countries where the potential of remote sensing in the above fields has been realized, the first step taken has been an inventory and mapping of natural resources and how they are being utilized.

In recognition of the importance of resource and resource use inventories, Stamp remarked that to use land or other resources to best advantage, a number of steps are required; (i) Survey, in which the present conditions were recorded; (ii) Analysis, in which the reasons for patterns were identified and (iii) planning, in which the future was designed.16/ This logical conception has been followed in industrialized countries and it has largely been responsible for the orderly spatial organization of resource use and management.

During the economic depression in Britain in the 1930s, Stamp organized the first land utilization survey of Britain which was followed by land capability mapping in 1938.17/ In the United States of America, land capability classification was one of the first steps taken to help land owners interpret soil maps and to facilitate management decisions based on soil potential and limitations in use.18/ Mitchell

also pointed out how "the Canada Land Inventory of resource potential for agriculture, forestry, recreation and wildlife, has been widely used for resource planning and management. According to him, the agricultural capability data help in delimiting agricultural lands; identifying submarginal farmland, consolidating farms into viable units, establishing a more equitable assessment base and indicating where urban and industrial development will least harm agricultural production."19/ In all the cited examples, conventional field survey techniques and aerial surveys were first used and the products now form the bases upon which they build upon. The advent of satellite remote sensing has therefore created a unique opportunity for all nations, especially countries like Nigeria which lack all resources and resource use inventories, to take advantage of this by giving national priority to the use of this technology for resource and resource use inventories and for preparation of land capability and suitability maps for rational resource planning and development.

Thus, given the level of knowledge of how to apply the technology in Nigeria and the currently existing constraints that exist, the most important area where the potential of the technology can be explored for immediate benefit in Nigeria is in the inventory of those natural resource components that have direct influence on agricultural production. These will include, soils, vegetation, water resources, landform and the current uses of the land. Such inventories will provide a fundamental basis for the determination of the capability/suitability of the land for various agricultural purposes; the rational allocation of the resources; the detection of both natural and human-induced changes; for impact statement and post-project impact assessment; and for proper policy formulation for the rational planning and development of the resources.

As indicated earlier, resource inventory is fundamental to all other areas (change detection, monitoring, forecasting and managing). However, given the non-existence of resource inventories and updated topographic spatial databases in Nigeria, a long-term benefit of the application of the technology will have a greater chance of success by taking the logical first step of a national programme on resource inventories without which all other potential advantages of remote sensing, including the powerful decision-making technology of geographic information systems would be very difficult to derive.

MAJOR CONSTRAINTS INHIBITING THE ADOPTION AND APPLICATION OF REMOTE SENSING IN NIGERIA

Because remote sensing technology has not been generally adopted in Nigeria beyond mere "appreciation" of its existence, it is important to examine the constraints which have inhibited its adoption in the country. Several of the problems have been identified elsewhere.20/ Therefore, only the major problems are briefly outlined. They include:

(i) The notion of "abundant resource endowment" with insufficient understanding of the term "resource" and the factors that condition

resource management has resulted in resource data and information being regarded as neutral activities which are therefore given residual consideration.

(ii) Unlike in the industrial countries, Nigeria does not enjoy a long history of scientific and technological education. The domain for secondary and higher education, until quite recently, was in the field of humanities. While education in the humanities is required to develop a politically conscious elite, the major sector of resources management and the whole complex of skills required depend upon science and technology. Nigeria, which recently embarked upon scientific and technological education, has continued to suffer from inadequate funding. The effect of this educational process on the adoption of remote sensing technology is the low level of awareness of the decision-makers and the senior civil servants about the possibilities and relevance of the technology to resource and socio-economic development. This situation has created only a passive appreciation of the technology. It has also prevented the formulation of appropriate national policy; the restructuring of the national/state natural resources agencies to accommodate the development and application of the technology, establishment of a functional national remote sensing centre; support for local training and education in the universities and agricultural research institutions and the unavailable local job opportunities for those who have acquired necessary training and education in the field.

(iii) The applications of conventional remote sensing was introduced to Nigeria during the colonial periods. During that period the application of aerial photography was carried out by colonial technical officers. At independence, most resource planners and managers had not acquired the necessary skills in photo-interpretation. Thus, the methodology of photo-interpretation had barely started to be adopted for resource investigation when Landsat became available. This situation did not enjoy the attitudinal and institutional changes that were required for the application of remote sensing.

(iv) The operative transfer mechanism has been driven largely by the technology itself without due consideration to the above factors and local knowledge system.21/ It has, in fact, reinforced the traditional wisdom that "science knows no boundaries." This maxim has been perceived to mean that research for development is best done by foreign experts. It has not been adequately realized that development cannot be imported but that it must be consistent with human dignity which is hard to preserve in condition of dependence on others and disrespect for indigenous culture.22/ In addition, there are limits to the transferability of technology and, less so, of scientific learning, even between one developed

country and another. Ecological and socio-cultural factors have to be recognized. Unfortunately, individuals who have benefitted from training programmes/seminars/workshops and the provision of remote sensing materials and interpretation equipment from industrialized countries and international organizations have little or no institutional support to build upon their knowledge. More importantly, nearly all remote sensing projects in Nigeria (very few on agriculture) have been contracted out to foreign firms who only supply the final products. Local universities and local research institutes have largely been ignored by the government agencies. Although the final products are hardly used, the non-utilization of local universities and research institutes has denied Nigeria the needed indigenous personnel for the propagation of the development and utilization of the technology. Yet, scientific understanding must reach a certain level of maturity before a successful application can be developed.23/

(v) As the configuration of a satellite is chosen to meet the specific objectives of its owner, the spectral bands and the channels selected for observation are the function of the parameters the owner or the country wants to observe, measure or collect. This in turn allows for the establishment of a long range economic and social plan but the non involvement of Nigeria in the field of space technology and remote sensing in particular has precluded the complex environmental situation and the unstructured land management practices to be fully taken into consideration. On this issue, Wickland further argued that the remote sensor developer must understand the biophysics of what is being remotely sensed, and someone (either the developer or user) must initiate a research programme to test the resource management system.24/ As a user nation, this has not been done. Thus, the complexity of the Nigerian environment and the unstructured agricultural land management system reduce the utility of the successful methodology developed in North America or Europe when applied to the Nigerian situation.

(vi) The above problems are further compounded by poor data accessibility and the current high cost of satellite data. As shown in Figure 2, Nigeria and its immediate neighbours are perhaps the only densely populated part of the world not covered by any ground receiving station. Thus, apart from the high cost of satellite data, temporally suitable satellite data for agricultural inventories are often not available. In the study of our agricultural resources in the semi-arid area of northwestern Nigeria, only December 1984 Landsat MSS data was available at the EROS Data Centre in Sioux Falls, South Dakota, United States. This data was found to be inappropriate for dry season agricultural inventories. In most cases monotemporal data is inadequate for agricultural investigations because of

temporal and spatial variations in the onset and cessation of rainfall. Even when assistance, in terms of supplies of satellite data, is given to institutions in Nigeria such as the UN/ESA assistance to five Nigerian institutions (as part of their International Space Year 1992 programmes), the absence of a ground receiving station covering Nigeria precluded the supply of the needed materials for areas not covered by the Maspalomas, Canary Islands, station.

Other constraints include:

(i) The lack of basic infrastructural facilities such as suitable equipment for both visual and digital processing, reproduction equipment, relevant textbooks and journals.

(ii) The lack of a functional national remote sensing centre. The role of such a centre in facilitating the adoption and the application of the technology, (given the roles which such centres have been, and are still playing in countries such as Argentina, Canada, France, India, Indonesia, Peru, Thailand, the United Kingdom and the United States) cannot be overemphasized.

(iii) The passive and uncooperative attitudes of the relevant professional bodies (such as the Nigerian Institute of surveyors, the Nigerian Society of Engineers, the Nigerian Agricultural Society, Soil Society of Nigeria, Nigerian Geo-science Society, the Nigerian Cartographic Association, etc.). These professional bodies have not shown appreciable interest in remote sensing. The Nigerian Society of Remote Sensing (NISORS) and the Nigerian Society for Photogrammetry and Remote Sensing (NSPRS) are relatively young and have not matured enough to have the necessary political power. They too have not been working together. With the passive attitude of these professional bodies, there exists no pressure group to influence government decision-makers or to enlighten the public about the relevance of the technology in their land and environmental resources utilization. Even without remote sensing, each professional body considers its own disciplinary area as most important, hence they do not cooperate.

(iv) The few available experts in Nigeria and in Africa work in absolute isolation. Hence they have not been able to benefit from successful research results carried out by others. This situation is further compounded by the lack of any remote sensing journal in Africa and the lack of a functional continental organization in the field of remote sensing.

(v) In Nigeria, there is no vendor dealing with image interpretation equipment and software packages. Although there are many computer vendors in

Nigeria, none of them deal with GIS software. Thus the acquisition of remotely sensed data and the hardware and software necessary for their interpretation requires foreign exchange which is not generally available.

(vi) There are inadequate local opportunities for education and training in the field of remote sensing. In fact, there is no Nigerian university with a viable remote sensing programme. The newly established universities of agriculture and universities of technology do not have functional remote sensing programmes.

(vii) Role definition, blind disciplinary support and the poor perception of the relevance of remote sensing and its modular character have made it difficult for those who have acquired the necessary training and education in the application of the technology to find employment in the field. In many cases they remain at their entry point without promotion. For instance, a geographer who has been trained in the use of remote sensing cannot get employment in agriculture in Nigeria. This situation discourages interested Nigerians from taking courses in remote sensing.

(viii) A new technology requires promotion. Such promotional activities require input from media organizations. Arising from the national perception of the technology and the negligence of the relevant professional organizations, the media organizations in Nigeria have not been able to perform this important activity.

If the potential of remote sensing technology is to be gainfully explored in Nigeria, solutions to the above constraints are urgently needed.

SOME THOUGHTS ON THE SOLUTION TO THE PROBLEMS

Possible resolution of the constraints identified above is discussed under the following broad areas:

(i) policy and institutional arrangements; and

(ii) area of need and level of application of remote sensing;

POLICY AND INSTITUTIONAL ARRANGEMENTS

The role of government, as exemplified by the governments of industrialized countries and some developing countries, is very vital to the development or adoption of any technology. Public decisions by government influence the manner in which society adapts to or utilizes the environment, the nature of spatial, temporal and functional allocation of resources and the form of regional development.25/ It is

therefore important that the Federal Government of Nigeria should recognize the contribution which the development and application of remote sensing can make towards the alleviation of the age-long economic problems by actively committing itself to its development and application. This commitment should result in the formulation and implementation of appropriate science and technology as well as resource management policies, the creation of appropriate institutions and agencies or the restructuring of the existing ones along multi-disciplinary lines, with favourable and long-term financial allocation.

It has to be noted that an institutional, rather than a resource or environmental crisis is a fundamental cause of the low level of remote sensing application in Nigeria. As noted by Craine and Kaynor and Howards, institutional arrangements are a composite of administrative structure, laws, policies, financial provision, customs and behaviours organized to deal with problems of life in a society.26/ Institutional arrangements are very important because:

> "All resource problems — overpopulation, hunger, poverty, fuel shortages, deforestation — are fundamentally institutional problems which warrant institutional solutions. The success or failure of resource management is intrinsically tied up with institutional structures — the pattern of agencies, laws and policies which pertain to resource issues." 27/

To create an enabling environment for the development and application of remote sensing technology in Nigeria, the following recommendations are suggested:

(i) A special seminar/workshop should be to be conducted for senior government officials in the Federal ministries and the relevant Commissioners in all the state ministries. For this purpose, the assistance of international organizations and specialized agencies in both industrialized and developing countries would be needed. Given two decades of propagation of the adoption of this technology and nothing to show for its success in Nigeria makes this recommendation very important. Without the full commitment of the government to the adoption of this revolutionary technology, no amount of aid, either for the transfer of the technology or for the improvement of agricultural and other resources can have a long-term effect.

(ii) The numerous agencies and committees that currently exist must be drastically restructured. The concurrent expenditure and the maintenance of the numerous agencies with overlapping functions leaves few funds for the implementation of their statutory responsibilities.

The restructuring should be based on multidisciplinary lines so the newly created organizations and institutions will be able to deal appropriately with the interdependent nature of the resources.

In addition to the restructuring of the existing resource management agencies, two additional agencies should be created:

(a) A functional national remote sensing centre (NRSC); and

(b) A national natural resource information centre (NNRIC)

These two agencies are very necessary for Nigeria. The need for a NRSC has been adequately dealt with by several authors.28/ The suggestion regarding the establishment of NNRIC is based in part on the extreme difficulty of gaining access to available resource information in the country. This has made all natural resources programmes costly, and time-consuming.

AREA OF NEED AND LEVEL OF APPLICATION

In a country lacking adequate information on natural resources and how they are utilized, the first priority areas where the potential of remote sensing can be of immediate benefit to agricultural programmes and other related fields is the inventory of those resource components that have direct influence on agriculture. These include soils, water resources, vegetation, landforms, settlement and rural feeder roads and agricultural land use patterns. Another important area is the updating of out-dated national topographic maps. Application in other areas as listed above will be difficult without the requisite inventories of the resource bases and their uses.

With regard to the appropriate level of interpretation, remote sensing systems have a modular characteristic which allow a gradual development starting, if necessary, at a low technological level with comparatively low costs, flexible and unsophisticated equipment. Three general levels with increasing technological complexity have been identified:

(i) Low technological level with simple photographic processing and visual interpretation methods;

(ii) Intermediate technological level with mainly analog interpretation methods, but more complex data handling and processing systems; and

(iii) High technological level with computer-assisted classification using digital and hybrid processing systems.29/

The three levels above correspond directly with progressively increasing investment and needs for trained staff to operate and maintain the more technically complex systems. Given the current low level knowledge of how to apply remote sensing in Nigeria, the adoption of the first two levels would seem to be adequate for conducting the necessary inventories suggested above. Several research findings in West

Africa, Indonesia and elsewhere have shown that visual analysis of enhanced composite films of satellite data, especially Landsat (TM) and SPOT (HRV) proved more superior than the conventional digital classification (maximum likelihood) for crop and rangelands inventory and mapping.30/. This suggestion does not mean that universities and other agencies with requisite facilities should not operate at the third level.

EDUCATION AND TRAINING

The need for education and training in the field of remote sensing cannot be overemphasized and it has received considerable attention.31/

Two major policy objectives to be fulfilled by education and training in remote sensing are:

(i) to achieve increased self-reliance, including mastering airborne and space observation techniques and applications and using them for the inventory and management of national resources; and

(ii) To attain a sufficient level of expertise to be able to negotiate at equal levels, system specifications and systems implementation for future satellite remote sensing systems suited to the particular needs of developing countries.32/

To achieve this in Nigeria, the cross section of the society requiring education and training at various levels and with specific orientations have been identified. They include decision-makers and their advisers, managerial persons in public and private organizations, engineers, scientists and researchers, professionals in various fields, educators (especially in tertiary institutions), technicians, the general public and the media organizations.

The current theoretical teaching in the fields of science and technology is inadequate. As noted by Spranger, "education must contribute to creating an increased awareness for the need to save the natural environment. Not only global concerns must be brought home to the people but also the need to take action decentrally at the grassroots level. This opens a wide field of initial and follow-up training measures."33/

It was for this reason that Nossin remarked that "It would be unwise to educate a student to become a geologist and not to train him at the same time or afterwards in photo interpretation...A 'dedicated' training programme will incorporate interpretation of remote sensing data — both visual and digital image analysis as well. In fact this is true for all earth sciences..."34/

There is a great need for the establishment of appropriate and integrated remote sensing programmes in the universities. Although the obstacles to realizing the benefits of remote sensing for economic and social development as well as the protection of the environment are complexly interlinked but they are all centred on education and training.

Notwithstanding the establishment of remote sensing programmes in the universities, the magnitude of surveying and mapping needs of the country and the lack of adequate numbers of knowledgeable persons in this field seem to suggest the need to establish, in carefully selected universities, faculties of surveying and mapping sciences with departments of remote sensing and GIS, land surveying/geodesy, photogrammetry and cartography.

PROFESSIONAL MOBILISATION

Given the active role being played individually and collectively by professional bodies in other nations and the resultant demands for the services of their members, as well as the way they contribute to the development of their countries and the advancement of their fields, professional organizations in Nigeria and many other African countries should take steps to increase their burden by strengthening their understanding of the contemporary and revolutionary technology of remote sensing. They should also be prepared to work together as a team to influence their governments in formulating appropriate policies. The professional organizations should also work together with educators to design and support appropriate educational and training programmes which would be responsive to the needs of the country.

In this regard, NISORS and NSPRS together with the assistance of international organizations need to conduct a special workshop for the representatives of the relevant national professional organizations. The main objective of the workshop will be to expose the various remote sensing application areas and to demonstrate to them the economic, social and environmental benefits of the technology.

It is also necessary for Nigerian professional organizations to become members of specialized international organizations in the field of space technology (e.g. IAF).

SUPPORT OF INTERNATIONAL ORGANIZATIONS AND SPECIALIZED NATIONAL AGENCIES

The support of international organizations and specialized agencies are required in all of the above areas. However, the following specific areas should be given priority:

(i) To encourage, and perhaps, make the adoption of the technology for resources planning and management a condition for all aids on resource and educational programmes. The global concern for food, energy and environment as well as the

solid evidence of the appropriateness of this technology makes this suggestion necessary. For instance FAO estimates that $1 billion spent on range management over the past 15 years was largely wasted.35/ And the World Bank found that most of the huge land clearing, irrigation-fed, tractor-driven schemes that dominated its rural development strategy in the 1960s and 1970s were tragically misconceived. One World Bank evaluation in 1985 puts the failure rate of its farm projects at 33 per cent in West Africa and 50 per cent in East Africa. It is highly-plausible that the inadequate resource information which could have been obtained through the application of remote sensing was largely responsible for such failures.36/ It is therefore necessary to conduct a special seminar/workshop, jointly organized by all resource and educationally-based international organizations and donor agencies for decision-makers, senior civil servants, resource and education managers and relevant professional organizations. Also, any programme on environmental protection being supported externally should have a strong remote sensing component because agriculture is a major contributor to degradation of the resource base and the environment.

(ii) Another area of support is the use of local experts in conducting resource and environmental projects. Often, several projects involving the application of remote sensing have been carried out without local experts. Two implications of this practice are:

(a) The results of such projects are generally not utilized and the required follow-up activities are never carried out; and

(b) Local experts, apart from the knowledge of how to apply remote sensing, also have indigenous knowledge of the environment and the people. For instance, conventional soil and vegetation classification mean very little or nothing to a rural farmer. Similarly, while the use of NDVI for rangelands mapping provides information on biomass (quantity), a Fulani pastoralist in northern Nigeria is more interested in fodder palatability (quality) and through several years of experience, he knows those areas with quality fodder grasses.37/ The employment of local experts will lead to capacity building of the local participants and sustenance of the required follow-up activities.

(iii) As already noted, over 95 per cent of Nigeria and its immediate neighbours are not covered by any ground receiving station. An attempt to establish a station in Ouagadougou failed. The difficulty being encountered by the countries in this sub-region in their efforts to obtain necessary data would only be alleviated by the establishment of a ground receiving station through the assistance of international organizations and industrialized and other developing countries. With further sensitization of the Federal Government of Nigeria as suggested in

this paper, basic physical and administrative infrastructure are likely to be provided by the government.

(iv) As the current cost of remote sensing data and other collateral materials are beyond the financial capabilities of most institutions and organizations, the assistance of international organizations and industrialized countries in these areas will lead to increase adoption and application of the technology. With particular reference to the universities and research institutes, the additional provision of reproduction equipment, text books and journals will enhance the teaching of remote sensing courses.

CONCLUSION

In 1938, General Warner Von Fritsch, the Chief of the German General Staff, remarked that "The nation with the best photo reconnaissance will win the war."38/ It happened. While we are fighting the war against hunger, poor quality of life and large-scale environmental degradation in Nigeria, as in most African countries, the quoted remark above can equally be interpreted that a nation with adequate knowledge of its resources has a greater chance of managing and developing the resources for the improvement of the quality of life of its people now and in the future, than one without such knowledge.

The experience of the last two decades has shown that careful and appropriate application of remote sensing and related technologies such as GIS can aid the supply of needed resource information required for the transformation of African agriculture. By developing, adapting, and applying these technologies industrialized countries and some developing countries have successfully met some of their national resource needs.

Since the economic status of every nation, and especially Nigeria, is largely a direct function of the efficiency of the use and management of its available natural resources, the centuries of poor national perspectives on the allocation and use of the resources have now contributed to rapid declines in resource quantity, quality, economic productivity and the standard of living. Although the causes of the problem are many and complex, the most fundamental and the least attended to, at least, in Nigeria, is the low level application of the technology of surveying and mapping, especially, remote sensing and GIS, to provide needed inventories and management information for the development of "abundant" natural resources.

Given the numerous success stories in the field of remote sensing, its potential for Nigeria and the constraints inhibiting its adoption were examined and possible solutions offered. As correctly observed by the Canada Centre for Remote Sensing (CCRS), only a wise development of natural resources in a nation will provide a real source of domestic support for growth and stability.39/ The success of this mission will depend, as outlined in this paper, on the ability of the nation to formulate and

implement a realistic national integrated resource policy. Such a policy would be very difficult to implement without adequate timely and spatial information on the status of natural resources.

The rapidly collapsing agriculture sector and the accompanying resource and environmental degradation cannot be wished away. It requires information which, under the present situation, can only be cost-effectively acquired through the dedicated and integrated application of remote sensing. This situation calls for a radical change in the current inadequate, and mostly disjointed, incremental and transferential agricultural resource management policies that make acquisition and utilization of resource information a residual matter. This new direction requires a sharply focused and implementable national resource policy that places a greater premium on the integration of remote sensing with local knowledge systems, broader social responsibility, a thorough understanding of the term "resource" and the interdependence of ecology, technology and economic development as well as the establishment of appropriate national research and development institutions with adequate enabling political support and infrastructural facilities to enable them to undertake pure and applied research and action-oriented projects on how remote sensing and its related technologies can, and should be applied to assist in the planning management and development of the shrinking and degraded natural resources.

Table 1

Urban/Rural Investment Allocations by all Governments in Selected Sectors of the Nigerian Economy 1970-1974 Development Plan.

Item	Total Capital Investment in Million Naira	Urban-Based Investment		Rural-Based Investment*	
		Million Naira	%	Million Naira	%
Industry	172.2	155.4	91.2	16.8	9.8
Electricity	90.6	80.6	89.0	10.0	11.0
Water & Sewage	103.4	84.4	71.6	19.0	18.4
Town & Country Planning	38.2	36.0	94.3	2.2	5.7
Education	277.8	196.8	70.9	81.0	29.1
Health	107.6	90.4	84.0	17.2	16.0
Social Welfare	24.0	22.0	91.7	2.0	8.3
Agriculture	746.2	615.4	82.5	130.8	17.5

Source: Areola (1982)
* The rural population is over 70%

Table 2a

Major Food Production in Nigeria

1971-71 and 1978-79

	Total Production ('000) Tonnes)									
	Millet	G/Corn	Beans	Yams	Maize	Cassava	Rice	Melon	Coco-Yams	Soya Beans
1971-72	2,835	3,794	801	9,766	1,274	4,516	279	63	880	1
1978-79	2,386	2,409	498	5,866	659	1,621	280	106	182	11
Percent change	-18.8	-36.5	-37.8	-39.9	-48.3	-64.1	+0.4	+68.3	-79.3	+1,000

Source: Are, 1986.

Table 2b

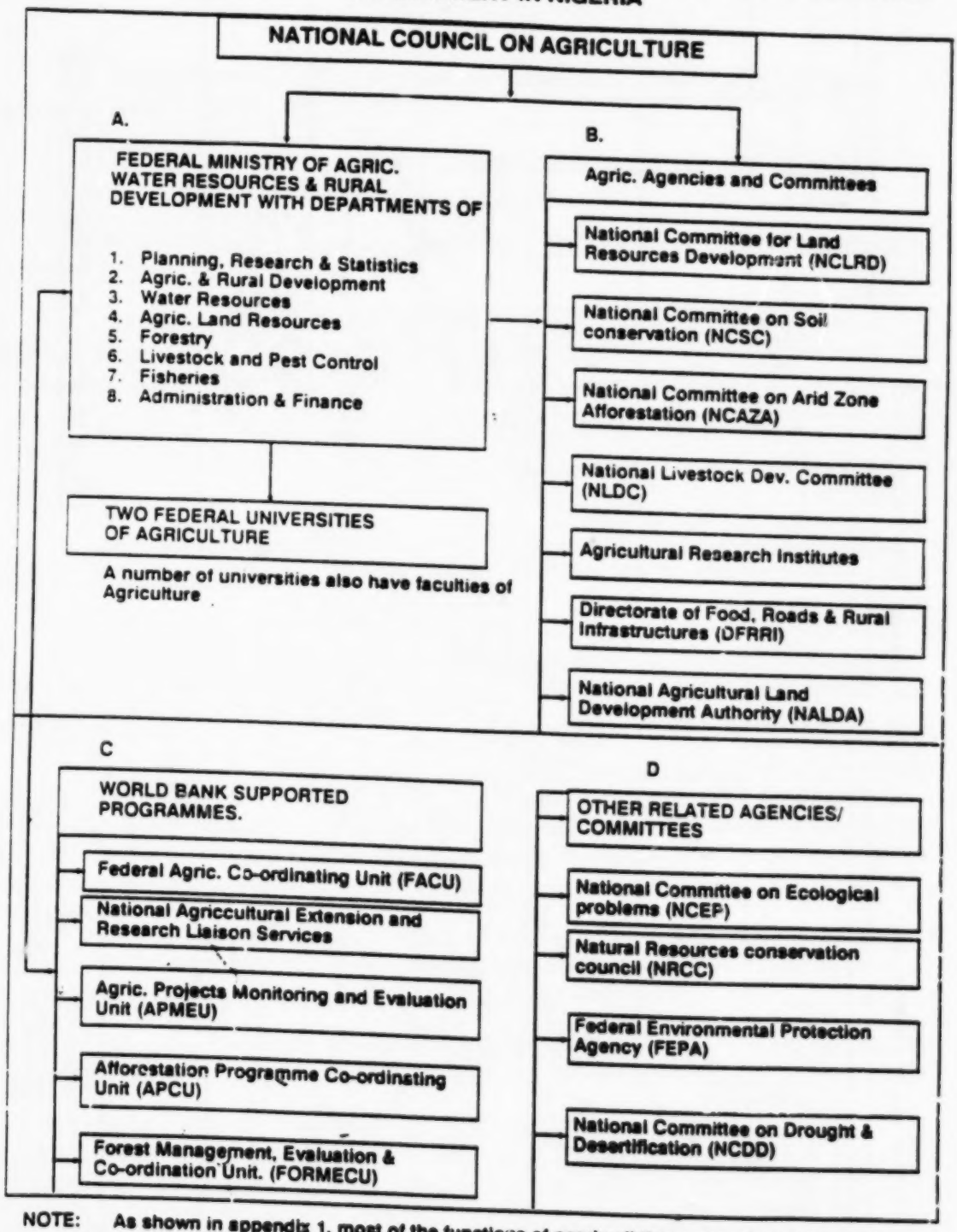
Major Nigeria's Primary Exports 1965 & 1976

Years	Cocoa ('000 tonnes)	Palm Oil ('000 tonnes)	Groundnuts ('000 tonnes)	Timber log sawn ('000m^3)	Cotton ('000 tonnes)	Crude Oil (10^6 tonnes)
1965	259	156	520	529	41	13.2
1976	228	3	2	28	-	95.9
% of change	-11.6	-98.1	-99.6	-94.7	*	626.6

Source: Adapted from Onyemelukwe, 1980

FIGURE 1

- GENERAL INSTITUTIONAL ARRANGEMENTS FOR AGRICULTURAL RESOURCE MANAGEMENT IN NIGERIA


NATIONAL COUNCIL ON AGRICULTURE
A.
FEDERAL MINISTRY OF AGRIC. WATER RESOURCES & RURAL DEVELOPMENT WITH DEPARTMENTS OF
1. Planning, Research & Statistics
2. Agric. & Rural Development
3. Water Resources
4. Agric. Land Resources
5. Forestry
6. Livestock and Pest Control
7. Fisheries
8. Administration & Finance
TWO FEDERAL UNIVERSITIES OF AGRICULTURE
A number of universities also have faculties of Agriculture
B.
Agric. Agencies and Committees
National Committee for Land Resources Development (NCLRD)
National Committee on Soil conservation (NCSC)
National Committee on Arid Zone Afforestation (NCAZA)
National Livestock Dev. Committee (NLDC)
Agricultural Research Institutes
Directorate of Food, Roads & Rural Infrastructures (DFRRI)
National Agricultural Land Development Authority (NALDA)
C
WORLD BANK SUPPORTED PROGRAMMES.
Federal Agric. Co-ordinating Unit (FACU)
National Agriccultural Extension and Research Liaison Services
Agric. Projects Monitoring and Evaluation Unit (APMEU)
Afforestation Programme Co-ordinsting Unit (APCU)
Forest Management, Evaluation & Co-ordination Unit. (FORMECU)
D
OTHER RELATED AGENCIES/ COMMITTEES
National Committee on Ecological problems (NCEP)
Natural Resources conservation council (NRCC)
Federal Environmental Protection Agency (FEPA)
National Committee on Drought & Desertification (NCDD)

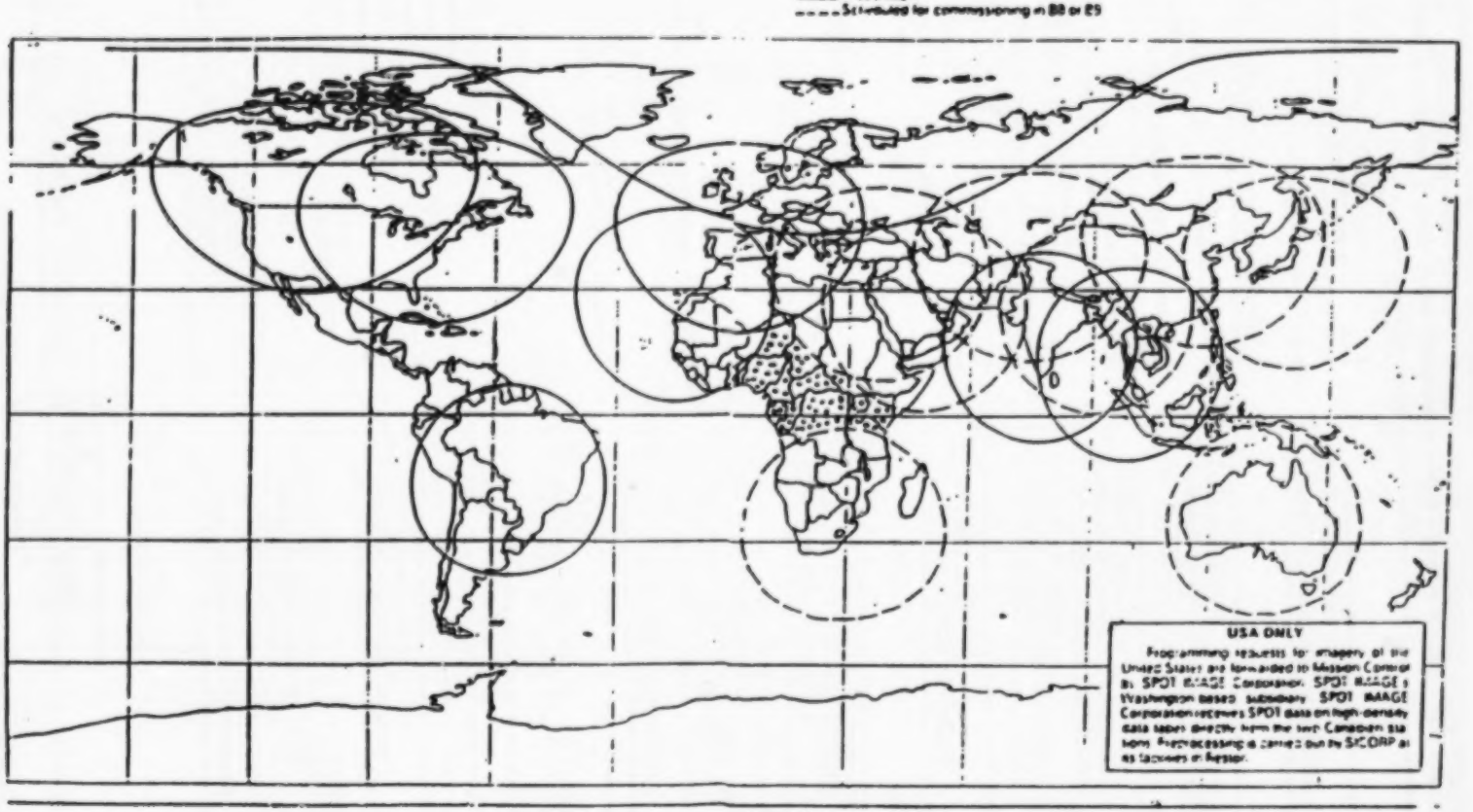
NOTE: As shown in appendix 1, most of the functions of nearly all these agencies and committes overlap. Their activities have ignored the only medium. - RESOURCE INFORMATION - for rational programme/project implementation and monitoring

RECEIVING STATIONS

Stations scheduled for commissioning in 1988 and 1989

Islamabad	Pakistan	SUPARCO
Hatoyama	Japan	NASDA
Pretoria	South Africa	CSIR
Riyad	Saudi Arabia	KACST
Beijing	China	SSTC
Alice Springs	Australia	NATMAP

Station	Country	Commissioning Date	Organization
Kiruna	Sweden	June 1986	ESRIS
Fucino	Italy	July 1987	ASI
Toulouse	France	September 1987	ESA
Kiel	Germany	August 1988	DFVLR
Kiruna	Sweden	July 1988	ESRIS



Area not covered by GRS

RCE SPOT Newsletter, July 1988, No 10, p 6

FIGURE 2

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SATELLITE REMOTE SENSING AND ITS APPLICATION TO THE NEEDS OF DEVELOPING COUNTRIES - AN ASIAN PERSPECTIVE*

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INTRODUCTION

Human history of two million years has gone through various stages and phases of development. The shifting of human practices for livelihood from hunting and gathering to domestication of wild animals and agricultural practices has only occurred during the last ten thousand years or so. The progress of civilization has accelerated since the 18th century industrial revolution began about two hundred years ago. This has opened a new era of mass production, mass consumption and mass disposal based on the behavioral principle of profit maximization. The industrial revolution and modern agricultural techniques have helped increase productivity but also introduced local, regional and global environmental problems.

Science and technology have also advanced through the ages. The first technological revolution was initiated 200 years ago. It was the application of steam power to transportation systems such as railroads and steamships, to mining and to machine production in factories. The second technological revolution, roughly 100 years ago, depended upon the spread of electricity for telegraph and telephone systems, lighting, power for turbines and elevators, allowing construction of skyscrapers and the advancement of chemistry, which for the first time allowed men to make products outside nature such as synthetics, petrochemical products and plastics. The third technological revolution will be aided by natural language communications, machine translation and certain expert's systems. There will be widespread robotics, electronic mail and messages, information retrieval on call, and services organized through interactive terminals. The range of possible and probable changes is enormous.

Historically, remote sensing technology has developed rapidly in the last few decades since the dawning of the space age with the launching of the Russian satellite Sputnik-1 on 4 October 1957. This was initiated as a part of the International Geophysical Year (IGY) in 1957-1958. The objective of the activities undertaken during

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IGY was the "common study of our planet by all nations for the benefit of all". This was followed by the launching of the first meteorological satellite (April 1960), and Earth resources satellites (the United States Landsat in July 1972 and the French SPOT in February 1986) with increasingly better resolution. It is to be noted that though the space age dawned in the 1950s, the wide applications of space technology started only in the 1960's with the resolution (fineness) of 1,000 m for meteorological satellites on the surface of the Earth. During the 1970s the technique improved and a ground resolution of about 100 m was achieved by Landsat and in the 1980s it improved to roughly 10 m (SPOT). During a decade of development of the technology, the resolution improved by an order of ten. In the future, hopefully, more and more improvements will be made. In the mid-1990s "Radarsat" will be launched by Canada and similar satellites will be launched by other nations for getting information on the Earth's resources and environment, even through clouds. The multi-spectral, multi-date and multi-stage remote sensing images and data are powerful tools for natural resources inventory, management and monitoring, both for the present and for the future.

Photographic techniques, map-making methodologies and aerial photography acquisition have a longer history starting from the mid-19th century (see outline in Appendix-A). The term Remote Sensing (RS) was coined by E.L. Pruitt of the United States in the 1960s and the first Geographic Information System (GIS) was developed in Canada in the 1960s. The interfaces and interaction between RS and GIS started in the 1970s, and their operational uses began in the 1980s. GIS is a data geo-referencing system for obtaining, storing, manipulating and retrieving data. Mini- and micro computers are usually employed for this purpose.

Asian countries, with the majority (about 3 billion) of the world's more than 5 billion inhabitants, are facing tremendous problems of overpopulation, deforestation, desertification, overgrazing, soil erosion and environmental pollution. These problems are complicated by man-made environmental degradation and natural recurrent disasters like floods, typhoons/cyclones, storm surges, droughts and earthquakes. Satellite-based remote sensing data offer some unique advantages of good coverage of a larger area at a time, a synoptic view of a given area, and repetitive coverage of the same area at regular intervals. These multi-temporal and multi-spectral remote sensing data could play a vital role in the management, assessment, and monitoring of natural resources (agriculture, forest, water, marine, geologic, etc.) as well as prediction and monitoring of disasters, climate change and environment degradation studies.

In the present paper an attempt has been made to elaborate some of the above issues related to the role of remote sensing and its application to the needs of the developing countries in Asian perspectives.

REMOTE SENSING AND ASIAN COUNTRIES

The Asia-Pacific region occupies 27 per cent of the solid Earth and accounts for 58 per cent of the global population. The population pressure has put the developing countries under stress and strain in terms of economic development. Remote sensing is particularly important for developing countries, because their economics are primarily based on development of natural resources. There is an urgent need to speed up completion of their resource database to be able to prepare realistic plans for their accelerated economic growth.

Major fields of applications of remote sensing are:

- Agriculture and vegetation;
- Water resources and hydrological regime studies;
- Conservation and environmental management;
- Engineering applications;
- Science and engineering in data acquisition;
- Geology and mineral exploration;
- Hazard monitoring and disaster mitigation;
- Urban planning and industrialization;
- Oceanography, marine resources and shipping;
- Atmospheric and stratospheric studies;
- Medical applications;
- Image processing and pattern recognition;
- Topographic mapping and automated cartography; and
- Geographic information systems (GIS).

Asian countries have made use of wide applications of remote sensing technology in the various above fields but they are in different phases and stages of development in terms of ground segments, space segments and application status. Almost all Asian countries have some sort of national remote sensing activities but only a few countries (China, India, Indonesia, Japan, Pakistan and Thailand) have more elaborate space and remote sensing programmes including ground and space segment development capabilities. In the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) region, there are at present about 20 full-fledged national remote sensing centres with numerous sub-centres in some countries and eight operating (and one non-operative) remote sensing satellite ground receiving stations with an investment on the order of $200 million in infrastructure. About 10,000 remote sensing scientists and technologists are working and about 1,000 projects related to remote sensing applications and development have been implemented in the past few years.

Remote sensing technology has been used extensively in the Asian countries particularly in the following studies:

- Environmentally Sound and Sustainable Development (ESSE) through integrated resource management;
- Global Climatic Change (GCC);
- Disasters Monitoring and Mitigation (DMM);
- Environmental degradation and hazards connected with disturbances in eco-balance, i.e. ecological imbalance;
- Causes and effects of greenhouse gases - global warming, sea level rise, depletion of ozone layer, etc; and
- Effects of El-Niño-Southern Oscillation (ENSO) and other climatic changes/variabilities/anomalies.

ENVIRONMENTALLY SOUND AND SUSTAINABLE DEVELOPMENT (ESSD)

Satellite remote sensing has now become an invaluable tool for the holistic and integrated management of the land and water resources as well as other resources. The information, when combined with conventional geo-political and socio-economic information/data and the integrated use of GIS, will provide timely input for conducting development activities. Many nations have already obtained immense benefits from this technology.

Sustainable development of natural resources requires an understanding of the mutual interdependencies and relationships of various resources (both renewable and non-renewable) and the identification of ecological problems at the micro level. These could be achieved through phases:

a) Collection and collation of conventional data and their evaluation.

b) Preparation of set of resource maps using existing maps, satellite/space-based remote sensing data and other collateral geo-political and socio-economic data. The thematic maps could be of the types as:

- Surface water bodies;
- Ground water potential zones;
- Potential zone for ground water recharge;
- Soil map including nature and erosion status;
- Existing land use and distribution of wastelands; and
- An integrated land and water resource map giving high priority areas for development of agriculture, fuel, fodder, soil conservation and afforestation.

c) Development of a package of appropriate strategies to address local resource management and environmental problems.

The completion of the above stages and their proper utilization in national development planning will definitely help in attaining ESSD. Indian experiences for National Natural Resources Management System (NNRMS) and its applications in the planning process could be profitably used by others.

GLOBAL CLIMATIC CHANGE (GCC)

The dynamic of the global environment is changing due to human intervention and other causes. The impact of greenhouse gases on the world environment has become a great concern for all humanity. The cause and effect of the greenhouse gases and other related phenomena has resulted in global warming and subsequent rise in sea levels. These will have tremendous socio-economic consequences for the low-lying countries. Satellite remote sensing could be used to monitor and measure various parameters related to GCC.

DISASTERS MONITORING AND MITIGATION (DMM)

Disasters have global impact. Most of the Asian countries are disaster-prone. The physiography, morphology and other natural conditions of the region have made them vulnerable to disasters and environmental hazards. The major universal disasters in the region are:

- Floods,
- Windstorms (hurricanes/typhoons/cyclones) and storm surges,
- Droughts,
- Abnormal rainfall, hailstorm and lightning,
- Nor'westers and tornadoes,
- Erosion and landslides,
- Earthquakes and volcanic eruptions,
- Saline intrusion,
- Industrial and other pollution, and
- Deforestation and depletion of forests.

The above disasters have disastrous effects on life and property and offset development efforts, particularly of the developing countries. Satellite remote sensing could play a vital role in the early warning, pre- and post-disaster events, damage assessment and other related activities. Asian countries are using this technology for these purposes but more coherent collaboration is needed, particularly on a regional basis.

Asian countries are also developing methodologies for mapping natural resources, and monitoring environmental changes and disasters. All the nations would greatly benefit from a regional cooperation programme which would provide a mechanism for:

- Exchanging information projects/specific disciplines of common interest;
- Sharing of training and infrastructure facilities and expertise; and
- Undertaking joint research projects of mutual interest.

PROBLEMS IN THE UTILIZATION OF REMOTE SENSING

The need for and applications of remote sensing in the developing countries have been explored by many nations but their full utilization is constrained by a number of factors:

- Lack of capital/operating cost,
- Limited access and non-availability of remote sensing data,
- Cloud coverage and low resolution,
- Dearth of trained manpower,
- Inappropriate and incomplete technology transfer, and
- Inadequate interfaces between the decision-makers/planners and technical personnel.

These problems are diverse in nature and at different stages and levels in various countries. There is no unique and no ready made solution to these problems. The problem-solution strategy may vary from country to country but a common strategy could be as follows:

- Highlighting the importance of the technology in national planning so that the political will and the commitment by the government is ensured.
- Initiation of more interactions between decision makers/planners and technical personnel.
- Development of adequate trained manpower and training facilities in phases.
- Complete technology transfer depending on the scope and extent of remote sensing applications in a particular country.
- Exchange of information and expertise between different countries, both regionally and internationally.
- Availability of remote sensing data at reasonable cost.
- Development of technology for high resolution and cloud penetration capability.
- Commercialization of remote sensing data in phases without hampering the interest of the developing countries and limiting maximum data use.

THE INTEGRATED REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM (RS-GIS)

By resolving some of the above problems, the utilization of an integrated RS-GIS could be an efficient tool in resource management and disaster monitoring on a global scale as well as for the Asian region. The use of RS-GIS in synchronization with conventional data will help in attaining environmentally sound and sustainable development (ESSD) in the Asian countries through rational management and monitoring of natural resources, environment, disasters, etc. Improvements in the data resolution, development of cloud penetration techniques, continuity and full data utilization, trained manpower capabilities and infrastructure facilities, are all needed to utilize remote sensing at the grassroots level and for operational activities. This calls for a close interaction and cooperation between the developed countries, developing countries, and the international agencies, including non-governmental organizations.

RS-GIS has wide applications in natural resources management, environment studies and disaster monitoring purposes. But there exists so many GIS's with different modes and models that it poses a problem with regard to international and regional cooperation. It is felt that GIS should be standardized with respect to methodology, specificity, terminology and inter-organization. Moreover, the use of a common format is needed or otherwise an easily exchangeable mode for databases should be developed. The database may include information on:

- Political boundary,
- Population,
- DTM (Digital Terrain Model),
- Land use,
- Soil,
- Geology,
- Land form (Geomorphology),
- Vegetation, and
- Planning development.

Data acquisition for digital databases including the fundamental geographic information noted above, with standardized codes should be developed with international aid according to the following phases:

LEVEL	GRID SIZE	SCALE
Global	10-20 km	(1:3,000,000 - 1:5,000,000)
Continental	4-8 km	(1:500,000 - 1:1,000,000)
National	250 m - 1 km	(1:200,000 - 1:250,000)
Regional	50-100 m	(1:50,000 - 1:100,000)
Local	10-50 m	(1:2,500 - 1:10,000)

RECOMMENDATIONS

Based on the above observations, the following recommendations are made:

1) Identification and preparation of a list of specific problems of each country and suggestions for specific solutions.

2) Development of a common strategy for solving the various problems on national, regional and international levels.

3) Development of infrastructure facilities and manpower capabilities in each country for full utilization of remote sensing technology in various fields.

4) Merger of conventional techniques with RS-GIS technology for effective and efficient use in the application field.

5) Strengthening the existing mechanism of information exchange by organizing more conferences and publication of newsletters and other documents. Networking arrangements could be established. Public awareness should be created.

6) Exchange of education and training capabilities and expertise through workshops, study tours, on-the-job training, short- and long-term courses, etc.

7) Undertaking of joint research projects and field application projects of mutual interest to promote appropriate inter-disciplinary studies on a regional basis.

8) Strengthened international collaboration between developed, developing, and international agencies including non-governmental organizations.

9) The Indian approach of GRAMSAT (satellites totally dedicated for rural development — with an effort to eradicate illiteracy in rural areas and to bring the fruits of science to the doorsteps of the grassroots of the society) should be supported by the international community to widen its scope and extent to other developing countries so that the benefits could be obtained by other Asian countries.

10) Strengthening and continuation of the efforts of the ESCAP/UNDP Regional Remote Sensing Programme.

11) More collaborative efforts in the context of participation in International Decade for Natural Disaster Reduction (IDNDR) 1990-99.

12) Effective contribution of the Asian countries in International Space Year - 1992 (ISY), the theme of which is Mission to Planet Earth, and activities of the International Geosphere-Biosphere Programme (IGBP).

13) Interactions with Global Resource Information Data Base (GRID) locations in Bangkok (Asia) and Nairobi (Africa) and other global data sources.

14) Establishment of an international centre/institute for remote sensing in one of the Asian countries with the functions of research, education, training consultancy, mapping, remote sensing, computer processing, GIS, etc. This institute will have the necessary linkages with exiting technical institutes in other countries. This institute should complement the activities of existing institutions without affecting their functions/funds.

CONCLUSIONS

Satellite remote sensing technology is one of the most modern, sophisticated, cost-effective and useful technologies, noted by its synoptic, repetitive and global coverage capability. Near real-time, accurate and up-to-date information/data are available through the use of satellite remote sensing technology. This could be used for the monitoring, management and conservation of the Earth's vitality and bio-diversity, which are needed to ensure the environmentally sound and sustainable development (ESSE) of the Earth's fragile resource base. The effective and efficient use of satellite remote sensing technology and the implementation of the recommendations (as suggested above) will help improve the quality of life of the people of the globe in general and the Asian countries in particular. Because of this, more extensive use of satellite remote sensing technology nationally, regionally and globally is encouraged and international support is recommended. An all-out effort is needed for this purpose.

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APPENDIX A

OUTLINE HISTORY OF REMOTE SENSING

YEAR	EVENT
1839	Louis Daguerre of Paris developed Photographic techniques.
1839	French Geodesist ARAGO used Photographs for mapping.
1849	Col. Aime Laussedat - Kites/balloons to take photography for preparing maps (father of photogrammetry).
1858	Tournachon - birds' eye view photograph of a village in France.
1860	Photography taken by balloons for military purposes - American Civil War.
1905	Aeroplane invented by Wright brothers.
1909	Acquisition of aerial photographs (First).
1914-19	World War I - Technology Advanced.
1925	Aerial photograph for topographic maps (South India) - Survey of India.
1935	Aerial photograph and Cartographic maps - Jessore area of Bangladesh.
1939-45	World War II - Technology Advanced
1948/50/60s	Aerial photograph for forest, water resource studies in Chittagong/Chittagong Hill Tracts and other areas of Bangladesh.
1957	Launching of Russian satellite Sputnik - I.
1960s	The term "Remote Sensing" coined and Geographic Information System (GIS) introduced.
1972	ERTS/LANDSAT of USA launched.
1986	SPOT of France launched.

REMOTE SENSING APPLICATIONS IN CHINA*

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INTRODUCTION

Since China launched her first satellite in 1970, space technology has developed quickly. Thirty-five satellites were manufactured and launched, including a recoverable satellite, a meteorological satellite, a communications satellite, a scientific experimental satellite and an Earth resources satellite. Meanwhile, the Government pays great attention to the development of space applications technology, especially in remote sensing applications which are a very useful tool for natural resources and environmental management.

As early as the 1950s, China started using aerial remote sensing for surveying and mapping, geological exploration and railroad bed selection. In the 1970s, China started extensive research on applications of space and aerial remote sensing, which included field spectral measurement as well as research on remote sensors, image processing equipment and applied experiments. By the end of the 1970s satellite data began to be used for natural resources investigation and environmental evaluation in the country. At the same time, some comprehensive application experiments of satellite remote sensing provided useful information for many management departments.

During the past decade, the emphasis of Chinese remote sensing development was on fundamental research, development of new sensors, image processing techniques, Geographic Information Systems (GIS) and remote sensing applications. A number of experimental application projects have been successfully undertaken in agriculture, forestry, hydrology, geology, oceanology, urban planning, etc. Many of them produced significant social and economic benefits.

Between 1981 and the present several remote sensing organizations have been established in China. Meanwhile, a preliminary remote sensing data acquisition system, data processing system and data application network have also been established. Remote sensing information has been widely and practically used in many important

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departments of the country. Now, a new Earth resource satellite is being manufactured as a cooperative undertaking between China and Brazil. A long-term development plan on remote sensing applications is also being formulated.

REMOTE SENSING ORGANIZATIONS

At present, China has more than 180 remote sensing organizations across the academic, educational, and industrial sectors. To promote remote sensing applications and development in the country, a National Remote Sensing Centre (NRSC) was established in April 1981 with the assistance of the United Nations and approved by the State Council. The centre is mandated:

a) to organize studies on policies of remote sensing development and to formulate related technical policies;

b) to draw up national long-term/annual remote sensing plans;

c) to coordinate remote sensing activities and projects;

d) to identify priority development projects and organize key national projects relevant to state economic construction;

e) to promote technical training and consultation services; and

f) to promote and coordinate international cooperation projects.

Now NRSC consists of eight departments with more than 3,000 scientists and engineers working in the fields of research and development, technical training, information service, aerial remote sensing, GIS and remote sensing ground stations.

In addition, many specialized remote sensing application agencies were also established by local governments and ministries in the last few years. These include a water resource remote sensing centre, a geological remote sensing centre and some provincial remote sensing centres. Their main goals are to apply remote sensing technology to social and economic development.

MAIN ACTIVITIES OF REMOTE SENSING APPLICATIONS IN THE LAST YEARS

To promote the applications of remote sensing in national economic construction, many important remote sensing projects, experiments, demonstrations and popularization activities have been organized in China in the last years. Some of them are described below:

Natural Disaster Monitoring and Evaluation

a) Flood Monitoring:

Since 1987, a series of flood monitoring experiments using remote sensing was organized by NRSC, e.g. in the areas of the Yellow River (1989) and the Huaihe River (1990). Last summer extensive flooding occurred in the south-east of China. The Flood Remote Sensing Information System was used for monitoring the flooded area (Huaihe River, Taihu Lake Basins). The system is composed of airborne SAR, image processing system and GIS. An area of 16,000 km^2 was surveyed under harsh weather conditions and many high quality image maps were produced which showed inundated fields, villages, roads and dams. Assisted by other technical methods such as radar images, mosaic maps and statistics from local governments, the system provided a database for decision-making in disaster relief. Satellite communications were used in flood monitoring which transmitted images to flood control headquarters in less than five hours.

(b) Forest Fires:

Forest fire monitoring systems, including information acquisition (mainly from meteorological satellite data and serial images), fast information processing services, an analysis system and forest fire forecasting are gradually being established in main forest areas.

(c) Earthquakes:

Scientists have already recognized and recorded the temperature increase before earthquakes, but the problem of identifying precursor phenomena and practical forecasting has not been answered. Only timely temperature data limited to some sites can be obtained with the method of fixed point network observations instead of dynamic evaluation data of temperatures in a large area within the seismogenic range. By using the thermal infrared radiation of Meteosat to detect the ground temperatures and analyzing temperature increases as a precursor of impending earthquakes, some obvious progress has been achieved in predicting earthquakes.

(d) Drought:

Experiments in north China on monitoring drought disasters by utilizing information from a meteorological satellite are in progress.

Other Remote Sensing Technology Application Programmes

a) Integrated Inventory of the "Three-North" Forest Shelter Belt

The main task is to use remote sensing information to register the types of forest resources, monitor forest disasters and survey forest areas in the North, Northwest, and Northeast of China (about 42 per cent of national territory). Meanwhile, a large number of forest maps, grassland maps, and land use maps on the scale of 1,100,000 have been produced. A resource and environment information system for this region has been developed.

b) Integrated Inventory of Soil Erosion in the Loess Plateau

Based on an inventory using aero-satellite remote sensing data and GIS, an important proposal for regional development has been made. It is useful for a comprehensive investigation of soil erosion and some small river basins.

c) Development for Remote Sensing Image Processing and GIS Software

Several workstations equipped with remote sensing processing systems and GIS have been established. For example, DIPNET 900 is a high performance, digital distribution information processing system. It can meet the needs of multi-window, multi-task, distributing network communication and management. Meanwhile, some GIS software packages have also been developed.

d) National DTM Database

With the help of remote sensing techniques, the digital terrain model (DTM) of the whole country at the scale of 1:1,000,000 has been established and topographic features were extracted. It has become an information base for many users of different departments in the country. The database can now be renewed and expanded.

e) Space Remote Sensing Data Acquisition System

The first Chinese remote sensing ground station was established in 1986 which can receive and process Landsat (MSS and TM) data. At the same time a network of meteorological satellite ground stations has been established which can receive and process meteorological satellite data. The data received by these stations are widely used by remote sensing users all over China.

f) Investigation of Mineral Resources

Applications of multi-source remote sensing data (TM, MSS, NOAA, AVHRR, airborne SAR, and aerial images) for mineral exploration were conducted. For example this data was used to assist in the exploration of gold and nonferrous metals in northwest China in 1990.

g) Application of Remote Sensing in Surveying and Mapping

Since the 1960s aerial photography has been the main method for surveying and mapping in China. However, since the 1970s satellite images and other remote sensing data have been used for medium or small scale mapping. Much progress has been made in this area, particularly in thematic mapping, e.g. land use mapping and natural resources mapping.

h) Technical Training

In the past years, the Chinese government has strengthened technical training for domestic and foreign participants. NRSC offers training programmes at different levels ranging from on-the-job training and short-term training to graduate-level training, and has provided a number of courses, workshops and seminars. Hundreds of technicians, not only from China but also from other developing countries, (including the Islamic Republic of Bangladesh, Islamic Republic of Iran, Jordan, Malaysia, Mongolia and Pakistan, among others), have been trained. The Wuhan Technical University of Surveying and Mapping offers two fellowships a year for participants from developing countries.

Some special remote sensing application workshops have been organized by the State Meteorological Administration, State Oceanography Administration, National Bureau of Surveying and Mapping, Chinese Academy of Sciences and other departments.

Remote Sensing Activities in 1992 and Future Plans

The application of remote sensing techniques has continuously been included in the Eighth Five-Year National Science and Technology Development Program (1991-1995). It indicates that the Chinese Government has attached increased importance to remote sensing. According to the policy of remote sensing development in China, the emphasis of the projects is to solve the vital problems in the country's social-economic development by means of remote sensing techniques. The main subjects are: Natural Disaster Prevention and Harnessing and Crop Yield Estimation. The main contents are described below:

a) Application for Relief of Damage by Natural Disasters

It concerns the establishment of a monitoring and evaluation system for national disasters, supported by an all-weather remote sensing monitoring network for floods, forest fires, earthquakes, drought and other natural disasters. It will include satellite data collection, processing, analysis and application systems. Satellite communication is used for image transmission from aircraft to the satellite and/or to the ground.

b) Monitoring of Global Environmental Changes

It could include monitoring of global change in desertification, atmospheric chemistry, vegetation, soil-erosion, deforestation and the marine environment. The emphasis could be on the Yangtze River basin, the Northwest Region, which is characterized by drought and desertification, and the Tibetan Plateau.

Three larger test areas have been selected for global change monitoring: the Xishuangbanna tropical forest test area (Yunna province), the Inner Mongolian grassland change test area, and the Loess Plateau soil erosion test area.

c) Yield Estimation for Main Crops

The main tasks include the application of remote sensing data to paddy (in the south) and wheat (in the north) yield estimation. Some test areas have already been established, and field work has begun. This includes Earth surface multi-spectrum collection (in paddy and wheat fields), data analysis and comparison.

d) Promotion of Remote Sensing Application

The basic goal of remote sensing development is its application. The Chinese government therefore pays more attention to promoting applications in such fields as natural resource surveying, dynamic monitoring of environmental change, information collection for regional planning, and monitoring for water and air pollution.

e) New Sensors Research and Development

Some new remote sensing instruments are being researched and manufactured, for example a microwave remote sensor, a serialbon SAR, an imagery spectrometer, data processing systems and work stations. A type of small meterological ground station has been developed which can receive and process meterological satellite data.

f) Technical Training

The main tasks are to provide some technical training opportunities for different programmes on different levels. Postgraduate courses are held at Beijing University. Other courses are mainly for local government managers.

g) Strengthening International Cooperation

China has similar economic development programmes as other developing countries. China is very interested in promoting space development cooperation with other countries. It is also interested in participating in international cooperative programmes focused on global change and the peaceful uses of outer space.

DATA COMMUNICATIONS SERVICE BY VSAT NETWORK IN THE PHILIPPINES*

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INTRODUCTION

Satellite communications is of particular importance to an archipelago like the Philippines. With some 7,100 islands, rugged forests and mountainous terrains, satellite communications technology offers the opportunity to leapfrog over existing difficulties challenging terrestrial-based microwave networks (see Figure 1). If harnessed correctly, it has the potential to significantly contribute to the provision of a wide array of services ranging from voice to facsimile and from data to video.

The continuous evolution of satellite and earth station technology since its inception more than 30 years ago has placed within reach technologies which are reliable, easily deployed, used and maintained. The Philippine government's recognition of the vital role of wireless communications was never more evident than during and after the series of natural calamities that hit the country and disrupted the existing microwave infrastructure. Aside from the obvious technological advantages over conventional communications technologies, satellites provide cost-effective solutions and fortify the country's unstable communications infrastructure.

THE TELECOMS MARKET

The Philippines has a very low national telephone density of 1.4 per 100 population. This scenario necessitates the use of satellite technology to fill the gap in unserved demand. Thus, the extensive use of VSAT technology to provide digitized voice circuits for use in private telephone networks and even public calling stations can be expected. Offering relief to a large base of communications users whose demand for basic telephone services remain unserved, it also represents a highly profitable market for the satellite carriers.

In the industrial and commercial environments, banks and financial institutions continue to be the biggest users of telecommunications services (Figure 2). Close to half of VSAT installations are being used by banks. The manufacturing sector is a distant second while other telecommunications carriers such as radio paging companies and

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* This paper, which was presented at the United Nations Workshop on Space Communications for Development, held at Seoul, Republic of Korea, 24-27 November 1992, does not necessarily reflect the views of the United Nations.

broadcast entities are likewise turning to satellite operators for their expansion requirements due to the inadequacy of terrestrial-based backbone facilities.

The experience of Philippine satellite communications operators is such that from their initial basket of point-to-point and point-to-multipoint leased channel services, they now realize that a great bulk of these leased facilities are being used for digitized voice applications. Hence they have naturally considered the long-term strategy of moving into services which bring telecommunications closer to a wider spectrum of the public and where the facilities of terrestrial-based network operators may be considered weak or inadequate.

SATELLITE CARRIERS

The full benefits of satellite communications have been largely denied to the Filipino people due to the prolonged financial and legal problems of what used to be the monopoly carrier in the country, Domestic Satellite Philippines, Inc. (DOMSAT). Established in 1978, DOMSAT had been providing interconnection or domestic interexchange service through a network of eleven earth stations. By the late 1980s, the difficulties that plagued the company had become so severe that despite customer requests, DOMSAT could not expand its service.

The situation prompted the government regulators to approve the applications for provisional authorities of new additional domestic satellite carriers, namely:

1. Liberty Broadcasting Network, Inc. (LBNI)

2. Clavecilla Radio Systems Corp. (CRS)

3. Capitol Wireless Inc. (CAPWIRE)

4. Philippine Long Distance Telephone Co. (PLDT)

5. International Communications Corp. (ICC)

Through an initial 300 micro-earth stations, LBNI proposes to provide point-to-multipoint domestic and international data transmission, digitized sound messages, store and forward facsimile services, and dedicated leased channels. CRS on the other hand teamed up with international record carrier Globe Mackay Cable and Radio Corp. (GMCR) to provide data, voice and simultaneous voice data (SVD) services.

Authorized to construct an initial satellite network of 20 earth stations, Capwire which is primarily an international data carrier, will now venture into "toll quality" voice telephone communications as a carrier's carrier. PLDT, the largest communications company in the country, has itself joined the VSAT bandwagon. Accounting for 95 per

cent of the nation's telephones, PLDT will presumably utilize satellite technology more aggressively in expanding its telephone backbone network.

In several countries VSAT technology has been exclusively identified with time division multiple access (TDMA) technology. At this point, however, it is important to note that in the Philippine scenario, VSAT broadly refers to satellite communications using antennas 4.0 m or less in diameter.

In November 1991, ICC installed its 10 m main hub earth station at the outskirts of metropolitan Manila. Unlike other authorized VSAT operators, however, ICC took a different opening strategy in the roll-out of its services by offering single channel per carrier (SCPC) and multiple channel per carrier (MCPC) facilities for easily deployed dedicated clear channel links. This move eventually led to the use of multiplex equipment that allows remote stations to split the high bandwidth and derive MCPC. The underlying rationale in the adoption of this strategy is to be able to immediately extend service using clear channel links which are simpler and easier to implement. Being relatively new in the country, TDMA is more complex and therefore requires a longer "learning curve".

DATACOMS OUTLOOK

Most Filipino industries rely on constant, on-line connectivity at medium to high data rates. VSATs have gained popularity because their cost is predictable (Figure 3). By comparison, the cost of leased land lines increase as locations are added and remote sites become more distant. In addition, VSAT networks have fewer points of failure, are quickly deployed and are more simply configured and managed. The advent of VSAT technology has enabled communications planners and managers in the country to establish and fast track their respective communications expansion programmes.

While digitized voice accounts for a significant percentage of customer usage (Figure 4), VSAT technology is also being used in computer on-line systems and wide area systems. The progress in the fields of ATM banking and credit verifications, as typical examples, was boosted significantly by the introduction of easy-to-deploy, readily available satellite circuits particularly in areas outside of the national capital region. At present, these installations are mostly MCPC in nature (Figure 4).

On the downside, the limiting factors in the use of satellite communications remain the cost relative to short distance and low volume channel requirements where terrestrial links remain competitive. At the moment, however, VSATs are gaining preference over microwave systems even for short distances and low volume circuit requirements due mainly to critical factors such as: i) the immediate need to distribute information among geographically diverse locations; ii) the declining cost of VSAT technology; and iii) the flexibility of VSAT installation.

The concept of establishing provincial satellite hubs, on the other hand, allows even-low-volume users to share a common 2.4 m or 4.8 m MCPC dish, thus achieving operational efficiencies and economies.

Traditional terrestrial facilities being used in the Philippines are analog, requiring a pair of modems for both ends to derive data circuits commonly running at 9.6 kbps (Figure 5). In a typical satellite-based configuration where end-to-end digital links are provided, two pairs (4 units) of modems are needed to complete a circuit. However, instead of the expensive V.29 or V.32 modems, low cost baseband modems will serve the purpose in the case of satellite communications.

In polled applications, delays or response time measured with terrestrial circuits have become the accepted parameters in the industry. For banking applications, the typical response time is 5 seconds. With satellite links, the single satellite hop presented significant delay or long response time because aside from the actual data, every poll has to pass through the link. This problem was later eliminated by the installation of poll-spoofing devices in all clear channel circuits carrying interactive poll traffic.

As equipment manufacturers such as Scientific Atlanta and Hughes, whose systems are the most widely used in the country, continue to develop even more cost-efficient technologies, more satellite dishes may be installed at customer premises. Applications such as point-of-sale verification (Figure 6) even for the smaller retail outlets may then be realized particularly as the Filipino consumer market is transformed into a "cashless" society. After the ATM boom in the late 1980s, the early 1990s are now witness to exciting developments in the credit card industry.

Whereas today video application of VSAT technology in the Philippines is limited to video uplink for the broadcast stations, the next few years will see the introduction of videoconferencing as a vital tool in doing business. Right now, the successful roll-out of videoconferencing service is being halted by what operators feel to be a market that may not be ripe for this new and "novel" service. Moreover, the prohibitive cost of equipment and lack of standards prevent third world satellite operators from developing tariffs that are both popular and profitable. It is hoped that with the rapid advancement in today's technology, these hurdles may be overcome soon.

CONCLUSION

As its communications infrastructure advances, the Philippine telecommunications landscape will continue to rely heavily on more robust satellite-based networks. Satellite technology will continue to play a key role in increasing and improving the quality of business communications to stimulate the country's economy. Satellite operators will therefore continue to aim to vigorously respond to the growing needs of business, commerce, and the government by bringing telecommunications closer to the people.

FIGURE 1

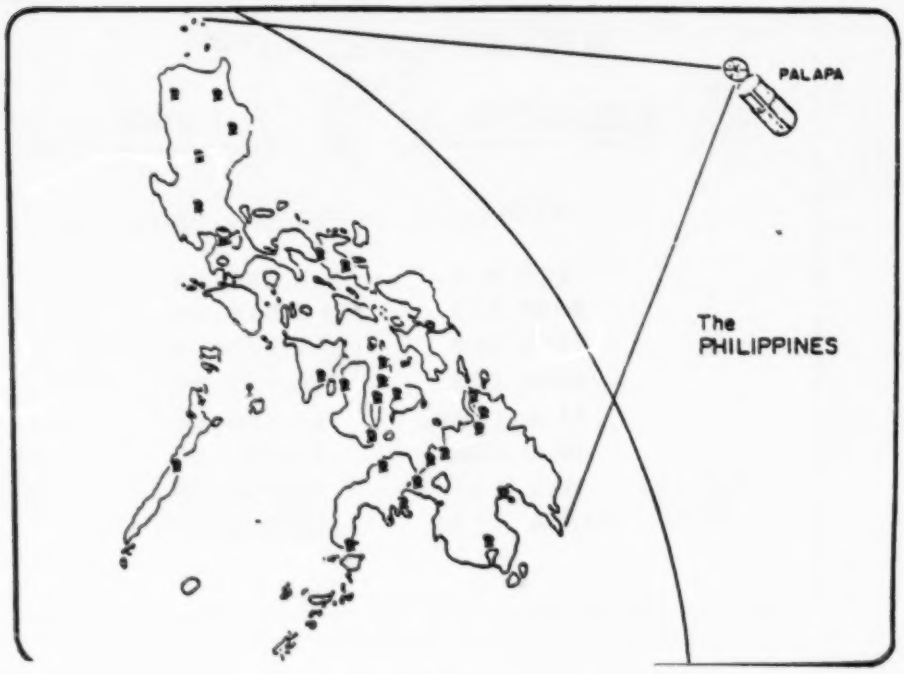


FIGURE 2

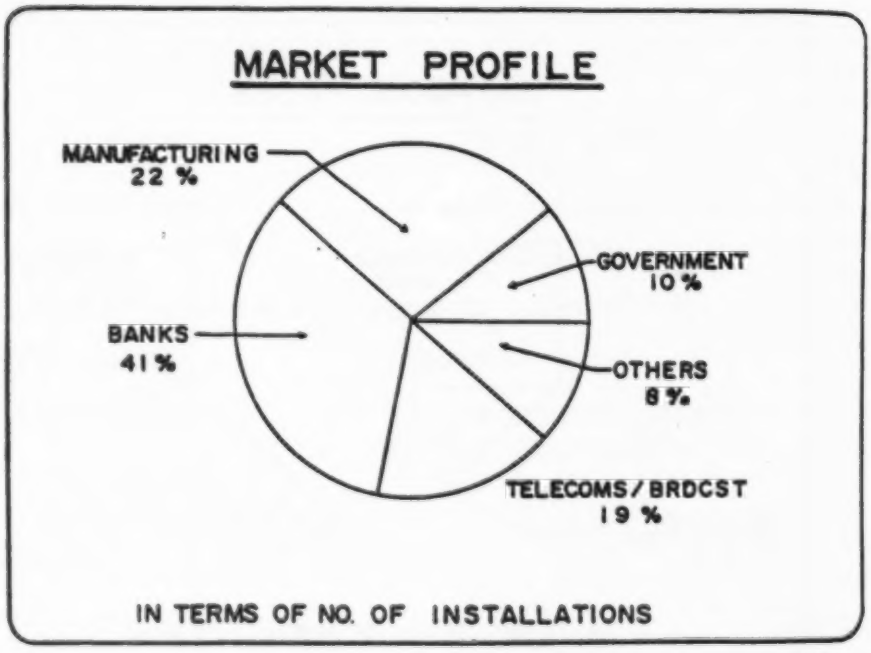


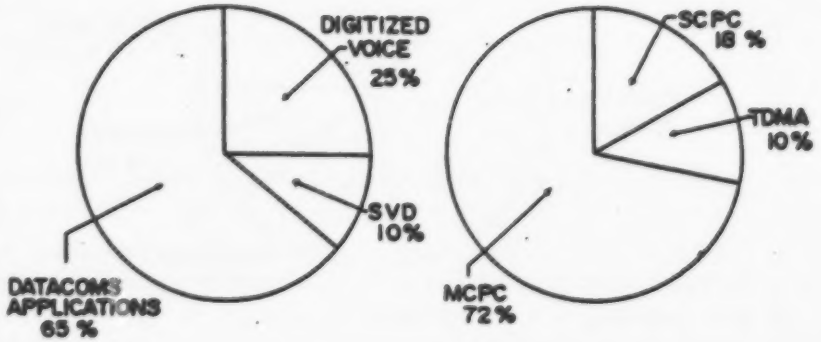
FIGURE 3

NTC-APPROVED RATES for DEDICATED SATELLITE LINKS

SPEED	MONTHLY RECURRING RATES
1200 BPS	P 5,534.00
2400 BPS	8,514.00
4800 BPS	14,190.00
9600 BPS	25,800.00
14.4 KBPS	34,830.00
16.0 KBPS	38,700.00
19.2 KBPS	46,440.00
56/64 KBPS	112,000.00

FIGURE 4

DATACOM PROFILE



IN TERMS OF NO. OF INSTALLATIONS

FIGURE 5

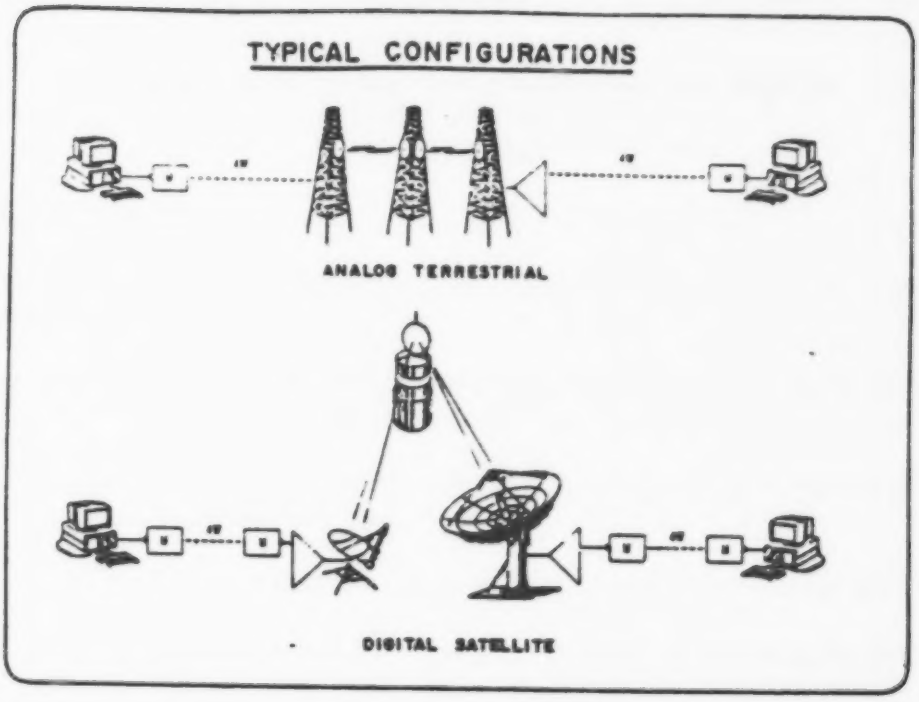


FIGURE 6

APPLICATIONS OF VSAT TECHNOLOGY

TODAY	NEAR FUTURE
• DIGITIZED VOICE	• CREDIT VERIFICATION
• FACSIMILE	• ELECTRONIC MAIL
• COMPUTER ONLINE SYSTEMS	• VIDEO CONFERENCING
• ATM BANKING	• TRUNKED RADIO
• DATA TRANSFER	• OTHER HIGHER - SPEED APPLICATIONS
• VIDEO UPLINK / BROADCASTING	
• PAGING	

THE INTERNATIONAL ULTRAVIOLET EXPLORER PROJECT*

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INTRODUCTION

The International Ultraviolet Explorer Project (IUE) is a general user space observatory and consists of:

- the IUE Spacecraft (S/C) containing a telescope and scientific instruments for spectroscopy in the ultraviolet;
- two IUE observatories for telemetry, telecommand and control (TTC) and scientific operations; and
- the IUE archive of public domain data (currently 81,000 ultraviolet spectra).

When IUE was launched on 26 January 1978, it was conceived as the first general user scientific space observatory. (Details of the spacecraft are given in table I.) The necessary innovations associated with this concept have had a profound effect on the development of the project over the unanticipated long life of the satellite, which currently is in its fourteenth year of successful orbital operation. The observations made available through the IUE project have revealed not only the open nature of the project but also that the short proprietary period of six months for the data has given a strong impetus to the unique modes of utilization of the data taken under the project. The high data rate for IUE throughout its lifetime (operating at 60 per cent efficiency), as well as the development of the IUE Archive during its build-up by the project has generated an unparalleled resource to study all classes of astronomical objects in the ultraviolet wavelength range from 115 nanometres (nm) to 320 nm. The combination of a relatively new observing window, the two spectral resolutions, the extremely flexible mode of operation and the rapid data delivery (24 hours after downlink), the careful management of the Archive and the easy access for all astronomers to the IUE resources, including both observing time and archival data, have made IUE the most successful telescope ever used.

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* This paper, which was presented at the the United Nations/European Space Agency Workshop on Basic Space Science for Development, held in Bangalore, India, from 30 April to 2 May 1991, does not necessarily reflect the views of the United Nations.

Although such a claim is difficult to substantiate, the number of papers based on the data is an accepted measure of success for any purely scientific project. For example, through June 1991 more than 2,000 research papers based on IUE data have appeared in the reference journals of astrophysics and solar system sciences. Data acquired with the S/C and data from the IUE Archive are often combined with new data. The average rate of 153 publication per year (see Figure 1), is unparalleled for any space sciences project or ground-based telescope. Another important aspect of the IUE project is the impact it has had on astrophysics education. In this respect, the sheet numbers are remarkable.

In Europe, at least 129 doctoral theses contain IUE results, while in the United States more than 100 Ph.D. theses have substantially used IUE data. This combined total of more than 230 Ph.D. theses based on IUE data implies that a significant fraction of all astronomy and astrophysics degrees granted during the last 10 years by the universities in Europe and the United States are based on data obtained with IUE. Never in the history of science has a single instrument had such a dramatic impact on the formation of a new generation of scientists. This is even more striking if one takes into consideration the many other large new facilities which have become available to astronomers in the last two decades.

In Section II of this paper, the IUE project and instruments are described; in section III, some of the important recent results obtained with IUE are highlighted; and in section IV some general aspects of the IUE projects are identified. The applicability and use of the IUE facilities to stimulate and develop the experience, knowledge and techniques needed for an important participation of scientists in developing countries in basic space sciences which will promote competitiveness with the scientific activities in the developed countries is also discussed.

VARIOUS ASPECTS OF THE IUE PROJECT

The Project

The IUE project is a joint effort between the United States National Aeronautics and Space Administration (NASA), the European Space Agency (ESA) and the Scientific and Engineering Research Council (SERC). The distribution for observation time is: 16 hours for NASA and 8 hours for ESA and SERC. The SERC time share is managed by ESA under the joint IUE Allocation Committee (IUEAC). NASA's time allocation is made independently. IUE time is allocated to scientists applying for observing time once a year (with the proposal deadline 15 December). The smallest unit of time normally allocated is 0.5 "Shift", (four hours), which can be applied by the Guest Observer (GO) to optimize the scientific return, respecting, of course, the operational limitations of the S/C. Both ESA and NASA support an IUE Observatory (Control and Science Centre), respectively in Spain, at the Villafrance del Castillo Satellite Tracking Station (VILSPA) and in the United States, at Goddard Space Flight Center (GSFC). Community demand

for IUE observing time is high and stable at close to three times over-subscription, and time allocation is not limited to the countries participating in the funding of the project (see table II).

The Spacecraft

The IUE spacecraft was launched on 26 January 1978 and since then has supported the science programme without significant performance degradation.1/ Although the S/C itself has suffered considerably during its 14 years of exposure to the outer space environment, it has been possible to adapt the on-board systems, as well as the ground system, to maintain the S/C performance. This has been possible through a judicious but not restrictive balance between scientific pressures and engineering constraints. A remarkable engineering activity associated with the IUE S/C was the design and implementation of a two-gyroscope based Attitude and Orbit Control System (AOCS) for a spacecraft requiring high precision 3-axis stabilization and all sky pointing. Since the third gyroscope of the AOCS is, practically speaking, replaced by a close coupling of the relations between the sun and the IUE orbit, it is not too surprising that the current two-gyro flight support system (FSS) AOCS functions possibly better than the original three-gyro AOCS. An additional benefit from IUE's gyro failures was the development of a new pointing determination system, the BETA-dot method.2/ This method uses the measurable effects of the S/C orbit around the sun and its dependence on the actual point of the S/C to recover the orientation of the S/C in space.

The Scientific Instruments

The IUE carries two spectrographs for low- and high-resolution spectrophotometry in the ultraviolet: the short wavelength (SW) from 115 nm to 195 nm and long wavelength (LW) for the range extending from 180 nm to 320 nm. These spectrographs are each equipped with two SEC cameras (see table III for current performance). In addition there are two Fine Error Sensors (FES) for fine guiding and field acquisition. The FESs are also useful as optical photometers, both to obtain supporting optical photometry of the sources observed in the UV as well as high-speed photometry, (100 millisecond) sampling, allowing continuous monitoring of stars in a broad bandpass centred at 550 nm. The cameras lose sensitivity only very slowly (2 per cent to 4 per cent per year) and show no degradation in definition. Although the most heavily used locations on the FES do lose sensitivity, there is hardly any overall sensitivity loss. Recently the FES has detected scattered solar radiation of currently undecided origin, but clearly associated with IUE. Preliminary studies suggest that this concerns either loose S/C coating or a form of contamination in the orbital environment of IUE (25,000-42,000 km).

The IUE Archive

The need for a data archive was recognized early in the project definition phase and the three agencies each made their own arrangements to serve their IUE user community.3/ The NASA IUE archive is at the National Science Space Data Center (NSSDC) at GSFC; the ESA IUE Archive is at the ESA IUE Observatory at VILSPA; and the SERC IUE Archive is at the Rutherford Appleton Laboratory (RAL). Each of these centres maintains complete up-to-date copies of the IUE Archive tapes. The software used to produce the reduced data tapes for the GO and entered in the archive is the IUE Spatial Image Processing system (IUESIPS).4/ Meticulous care has been taken by the project to maintain output compatibility of the IUESIPS software between the two IUE observatories. The size of the science data in the IUE Archive after 13 years of orbital operation is given in table IV. With the advances of technological capabilities, different subsets of the IUE Archive have been created to facilitate access to the data. Of those, the low-resolution spectra in the Uniform Low Dispersion Archive (ULDA)/USSP National Hosts should receive special attention.5/ The ULDA concept is especially promising to bring archives such as the IUE Archive within the reach of scientists in developing countries, while the data are still new. It can be seen in table V that by far the largest fraction of IUE Archival data usage is supported through the ULDA. Currently, 15 national hosts distribute, with minimal support, the IUE low-resolution data to some 500 registered users from 30 countries.

HIGHLIGHTS OF IUE RESEARCH

It is obviously not possible to present here an overview of all IUE research. It is possible, however, to highlight a few important results which will also illustrate the strong points of the IUE project, both in concept as well as in its operational functions.6/ Typical results for the inventiveness with which IUE has been used by the astronomical community are discussed and the breadth of the IUE science programme is illustrated. The specific topics addressed will be:

(a) The observational programme associated with Supernova 1987A;
(b) The general programme of Comet observations; and
(c) The first active galactic nuclei (AGN) campaign: The Seyfert (NGC) 5548.

Supernova 1987A

From an observational point of view, it is obvious that the discovery of a supernova (SN) in our nearest neighbour galaxy, the Large Magellanic Cloud, was the event of the century. The continued operation of IUE during the explosion and decay of the supernova was extremely fortuitous. Only 13 hours after the supernova's discovery by Ian Shelton, the IUE S/C was directed towards SN 1987A and 100 hours of uninterrupted IUE observation were directly applied to the very fast early development of the supernova.7/ Its brightness in the UV decreased at a rate of 2.2

magnitude per day during the first two days. The first spectrum, taken only 36 hours after the core collapse, showed a hot (T 50,000° k) continuum which dropped rapidly to the canonical value around 7,500°k.8/ The (P) Cygni profiles suggested expansion velocities around 35,000 km/sec. The rapid decrease in brightness was the consequence of the combination of the drop in temperature itself with the corresponding rapid increase of the opacity in the atmosphere of the supernova, all suggesting a relatively small mass supernova. The subsequent rapid disappearance of the supernova itself at short wavelengths had the unanticipated consequence that through the UV observations the progenitor star of supernova 1987A could be ambiguously identified more than three years before this could accomplished through optical observations.9/

It was confirmed that the B3Ia blue supergiant Sk-69°202 (V=12.5 mag) had disappeared and was the star that caused the supernova explosion by its collapse. These types of stars had not been known to explode as supernovae, but could be understood theoretically fairly soon after its nature had been established. After a few months, narrow emission lines appeared in the short wavelength ultraviolet spectra. These lines were identified with elements at various stages of ionization: NV1238-1240, NIV]1483-1486, HeII1640, OIII]1664, NIII1747-1754 and CIII]1907-1909. The abundances measured from these lines (N/C=7.8+/-4 and N/0=1.6+/-0.8 corresponding to respectively 37 and 12 times solar) show clearly that we are dealing with CNO-processed material.10/ The time evolution of these lines allowed a detailed modelling of this structure and a ring of a two density medium was required to explain the difference in the time development curves of the different lines. This could only be satisfactorily matched with a mainly light travel dominated case and is a good measure for the actual size of this gas ring (D=500 lightdays). The combination of these results with the images of this gas ring taken four years later by the Hubble Space Telescope, allowed a direct measurement of its angular size and led to a new a direct distance determination of the distance to the Large Magellanic Cloud. This was found to be 51.5+/-2.5 kilo parsec (kpc).11/ This is one of the best demonstrations of the far-reaching importance of the results of applying original observing methods with the IUE in combination with other instruments and astrophysical theory. Also, the rapid response in the early stages of the explosion, when the star was still bright has allowed scientists to make an extremely detailed atlas of the interstellar lines, which characterize the interstellar matter between us and the supernova, thereby enabling a discrimination of the velocity fields belonging to the Galaxy and the LMC.12/

Target of Opportunity (ToO) programme: Comets

Due to the fact that a number of phenomena, such as first-time Comets, Novae and Supernovae, are unpredictable, the IUE project was established with a well-defined ToO programme, organized around a number of specialists interested in studying such objects with the IUE. They form the ToO teams, which support the Observatory staff during these events, in defining the most balanced observing programme.

The Cometary ToO programme is a good example of the enormous increase in understanding brought about by the IUE programme, with 40 comets observed between 1978 and 1990, both in the specifics of the more than 700 ultraviolet Comet spectra and the highlights of cometary physics.13/ The rapid response capabilities have now enabled us to state with assurance that we can summarize the characteristics of comets as a class. The first surprise was that comets are an extremely homogenous group in terms of their gas emissions. The similarity between the different types of comets has firmly established that cometary ice is essentially the same in all comets.

Only in two basic characteristics do we see differences between comets: the gas-to-dust ratio, which can vary by orders of magnitude from one comet to another, and the variable strength of the Carbon I (CI) multiplets and some CO bands. The cause of the first difference is most likely associated with the specifics of previous perihelium passages of the comet and the second could be related to a currently unidentified collisional dissociation of CO in the cometary coma. An important result was the first detection of the S_2 molecule in any astronomical object, close to the cometary nucleus in comet IRAS-Araki-Alcock 18/, which passed very close by the Earth (at 0.032 A.U. and moving over the sky at a rate of 2°/ hr).14/ Finally, mention should be made of the continuous IUE observations during the last perihelium passage of Halley's Comet. The continuous quantitative monitoring of the evaporation rate of molecules like CO_2 and H_2O has made it possible to place the many single pass observations in the context of the continuous evolution of the comet during its approach to the sun as well as its return to interplanetary space.15/

AGN broad-line mapping: NGC 5548

Until a few years ago our understanding of active galactic nuclei (AGN) appeared to be proceeding well. The major problems associated with the anomalous emission in ratios shown in these objects seemed to be well understood through the general central photoionization theories for relatively high-density gas ($N = 10^9$ cm^{-3}) and a thin accretion disk around a massive Black Hole. Continued studies in the UV with IUE, however, suggested that the time scales involved in the brightness variations of well studied Seyfert I galaxies are not consistent with these models for the central source of photoionization. As a consequence, plans were made to formulate observational programmes which would be able to clarify this question. The expected high spatial resolution of the Hubble Space Telescope (HST) would not solve the problem, because the expected sizes for the BLR are smaller than could be resolved with HST, even for the nearest AGNs. During an ESA/IUE AGN workshop held at Segovia, Spain, in 1987 the problems were highlighted and a massive collaborative effort was developed. A total of 90 astronomers joined forces in a common proposal to request from both ESA and NASA selection committees for a total of 60 observations (one observation every four days) to determine the size of the BLR in NGC 5548 through an extensive time delay study.16/ (See figure 4.) These data are important in various ways since they demonstrate without a doubt that the general concept of photoionization for AGN is

correct. On the other hand, the delays measured for the emission lines with respect to the F(135 nm) are far too small to be compatible with variations in the accretion rate. The distances from the ionizing source found for the BLR gas were also different depending on the excitation, e.g., HeII1640 four days; CIV1549 eight days; Ly-alpha 12 days; and CIII 26 days. This strongly suggests ionization stratification in the BLR and thus indicates that one will have to go to considerably more complex physical and geometrical models than were applied until now. It is hoped that these studies will be continued to allow the determination of one of the most fundamental tests of the physics of AGN: the determination of the existence or absence of a luminosity-size relation, which is a direct consequence of the nature of the gravitational energy release driven by the accretion on a massive Black Hole. The existence of such a relation would give strong support to the Black Hole models for AGN.

WHERE TO GO FROM HERE WITH IUE

It is clear from the science highlighted above that the IUE project has developed in ways which could not have been foreseen a few years ago, let alone at the time of launch. Since it is clear that the enormous diversity of science performed with IUE has only been possible through the direct involvement of a large scientific community in the definition of the science programme, the IUE project is ideally suited for astrophysicists who want to begin participating in space astrophysics. It is worthwhile to point out that a programme such as IUE, with facilities that offer the flexibility typical of a normal observatory, with a convenient geosynchronous orbit, an open public philosophy from launch onward, with rapid data delivery in physics units, and UV capability are not envisioned for the coming decades. The one exception in the science programmes of the major space agencies is the SPECTRUM-UV Phase A study of the Russian Federation, Italy and Germany. This has two important consequences:

1. After the demise of IUE, the current drive to study dynamic astronomy in the UV will come to a halt for at least one generation of future astronomers; and

2. Unless IUE is now used to address those problems for which it is exceptionally suited, they will not be addressed in the foreseeable future.

For the developing countries, IUE represents an important tool to develop knowledge and experience in general space astrophysics because it is a very open project with wide scientific applicability. The IUE community is very open to collaboration from many quarters since it has learned the lesson that the full capability of IUE can only be exploited through collaboration and participation of the worldwide community of astronomers. The IUE project itself has always been supportive of astronomers, not only those from major institutes but also those from small regional institutes with limited resources. Therefore, participation in the IUE science programme is not costly and will allow full competitive research to be conducted by people of moderate means. Access to the IUE archives is equally simple and can to a large extent be fully organized

in a national context such as the Uniform Law Dispersion Archive.

Another important factor which could allow someone to initiate new work is of course the development of a successor satellite to IUE with similar, limited capabilities but more light collecting power. By keeping to similar conceptual simplicity with a project it is possible to keep within reasonable cost limits and be operational within a reasonable timeframe, such as five to seven years. Such an instrument would allow many major breakthroughs in many areas of astrophysics and would open new horizons.

Table I. STATUS IUE SPACECRAFT

ORBIT	: 3-axis stabilized S/C in geosynchronous orbit
GYROSCOPES	: Originally 6; Currently 2 (failed: 1979, 1981,1982, 1985)
SLEWING	: 4 Reaction wheels; 1 backup (accuracy : 10^{-3} arcsec/sec)
HYDRAZINE	: Momentum dumping and Station Keeping; 25 year supply (16 Kg)
SOLAR PANELS	: Power Positive between 30° and 112° Solar Aspect angle
BATTERIES	: 2 Fully functional; support Earth Shadows
COMPUTERS	: 3 Memory banks (12K): 8K standard; 4K Backup system

TABLE II. Non-ESA participation and overall demand for ESA IUE Observing time.

	9th year	10th year	11th year	12th year	13th year	14th year
Non-ESA P.I./ Co-I. Percentage(1)	3/18 4.0 %	3/17 5.0%	5/10 4.5%	7/9 4.0%	5/14 5.1%	2/11 3.5%
Shifts Requested	877	945	763	727	842	878
Load (2) Factor	*2.9*	*3.2*	*2.5*	*2.4*	*2.8*	*2.9*

(1) This gives the percentage of successful applicants from non-ESA members states with respect to all investigators participating in approved IUE proposals.
(2) Load factor is calculated on the basis of the 300 day year available for the GO scientific program(VILSPA Staff programs, which are also competitively assigned are not included).

Table III. IUE SCIENTIFIC INSTRUMENTS

TELESCOPE	: 45 cm f/15 Ritchey-Chretien Cassegrain
SPECTROGRAPHS:	Echelle (115 nm to 198 nm and 180 nm to 320 nm)
APERTURES	: 3"; and 10" by 20"; image quality 2"
RESOLUTION	: $1.8*10^4$: 0.008 nm @ 140nm;(17 $Kmsec^{-1}$)
	: $1.3*10^4$: 0.017 nm @ 260nm;(20 $Kmsec^{-1}$)
	: 270 in low resolution mode @ 150nm
	: 400 in low resolution mode @ 270nm
CAMERAS 1)	
SWP	: fully operational;sensitivity: $2*10^{-15}$
SWR	: Not operational
LWP	: fully operational;sensitivity: $1*10^{-15}$
LWR	: operational backup at $2*10^{-15}$
FES #2	: fully operational; limiting mag: V= 14.0
FES #1	: operational backup; limiting mag:V= 13.25

1) Units for Camera Sensitivity are: ergs sec^{-1} cm^{-2} A^{-1}

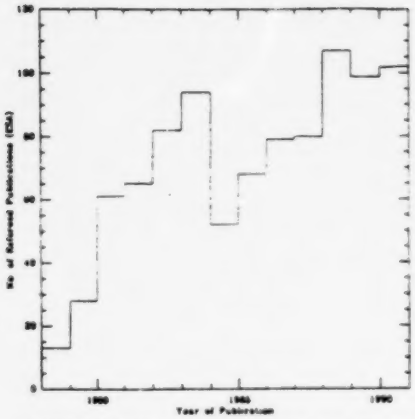

Figure 1.This histogram shows the number of refereed papers published yearly, based on IUE data obtained under the ESA IUE Project.The differences in trend are associated with new phases in the usage of the IUE Spacecraft,as well as the IUE Archive and indicate renovations of the research due to enhanced utilisation of the Archive.Considering the total number of Astrophysicists in Europe,the current level of 100 papers per year represents most likely the peak capacity of the astrophysical community in Europe.

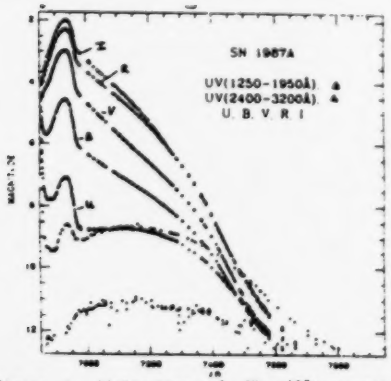

Figure 2. Lightcurves of SN 1987A spanning nearly a decade in frequency. These show the importance of observations over a broad range, since it is clear that the energy maximum shifts considerably with time. Note that the first observations were completely dominated by the UV, while at later stages most of the emission takes place in the red and even later (not shown here) the peak falls at wavelengths beyond 1000 nm. To be able to determine the bolometric lightcurve, critical for the understanding of Supernova explosions, reliably it is vital to observe the radiative decay over a wide range of frequencies.

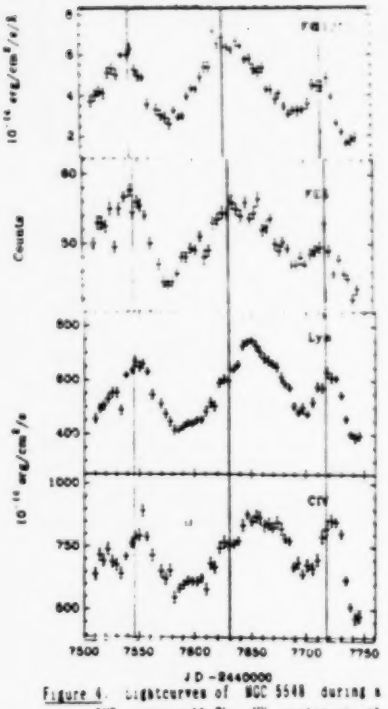

Figure 4. Lightcurves of NGC 5548 during a major IUE campaign[19]. The UV continuum at 135nm and the visual continuum at 550nm (FES) are at the top. The lower two diagrams show the emission lines of Ly-alpha1216 and CIV1549. Vertical lines mark the UV maxima. Note that the two continuum windows vary simultaneously, while the lines show a clear delay in the response to the continuum variations. The size of the delay depends on the ionisation of the line.Also there appears a suggestion that the delay is not the same for all three cycles.

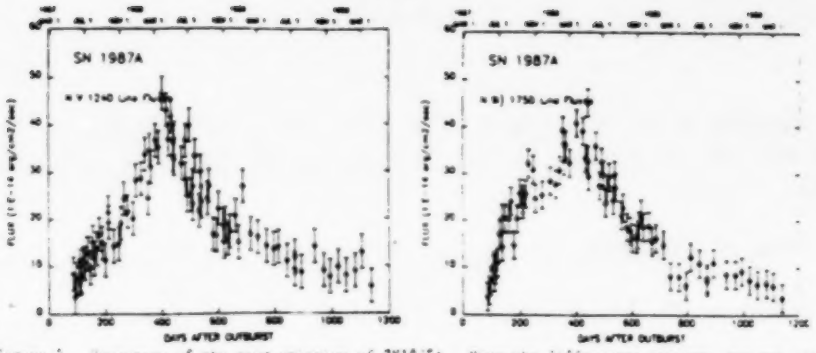

Figure 1. Variation of the ring emission of SN1987A. Note the differences between the two lines with different ionization potential and density dependence. The NV1240 lightcurve (left) is nearly completely dominated by lighttravel effects.Although the extended tail at day 600 is a consequence of the recombination time dominated radiation from low density regions. The NIII]1750 line(right) shows a complex mixture of the two phenomena also influenced by the fact that the major part of the radiative output in this multiplet shifts between the different components. Also here the N_e<1000 cm^{-3} tail is quite conspicuous.

Table IV. Contents of IUE Archive (June 1991)

All data			# of items	Total	
Raw image	0.59	Mbyte	81,242	47.9	Gbyte
Photometric	1.18	,,	81,242	95.9	,,
Label Info.	0.009	,,	81,242	0.7	,,
---- Low resolution					
ELBL	0.67	,,	54,242	36.3	,,
Merged	0.015	,,	54,242	0.8	,,
---- High Resolution					
Merged SW	0.66	,,	13,430	8.9	,,
Merged LW	0.74	,,	13,370	9.9	,,
Total			81,242	200.4	Gbyte

Table V. Usage statistics of the IUE Archives (June, 1991)

	Total	Annual Rate	% annual	% total
13 yrs VILSPA- Tape	45,127	3,471	6.9	14.9
3 yrs ULDA/USSP	74,000	24,666	49.3	24.5
8 yrs NSSDC	30,000	3,750	7.5	9.9
12 yrs RAL	21,075	1,686	3.4	7.0
8 yrs RDAF	100,000	12,500	25.0	33.1
8 yrs CURDAF	32,000	4,000	8.0	10.6
Total:	302,202	50,073		

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CONTRIBUTION OF NOAA-AVHRR DATA IN RESOURCES MANAGEMENT, ENVIRONMENTAL ASSESSMENT AND GLOBAL CHANGE STUDIES IN THE SOUTHERN REGION OF SOUTH AMERICA*

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INTRODUCTION

The observation of vegetative phenology on land surfaces is important to determine the biotic resources of the Earth, to study the way they change and their influence on the temporal organization, evolution and functioning of land use. The spatial and temporal variation of the vegetative cover are affected by humanity's activities and nature. Monitoring of vegetative dynamics is therefore relevant in estimating the climatological and human impact on the Earth's biotic environment.

Snow cover, jointly with snow depth is an important parameter for determining the extent of water runoff in river basins and determining the extent of snow covered areas is important in many countries for achieving improved control over drinking water supplies through irrigation. Snow cover also plays an important role in climatic processes and weather forecasting due to the fact that it can affect surface and air temperature, atmospheric circulation patterns, storm tracks, surface albedo, radiation balance, evaporation and precipitation.

The patterns of sea surface temperatures (SST) in spatial scales ranging from local to global, and on temporal scales ranging from a few days up to months or years are of considerable interest to scientists in fields such as oceanography and meteorology. Weather patterns and climate changes are known to be significantly influenced by long term variations in the SST. Major water masses and current systems in the world's oceans can be identified by differences in surface temperatures, as well as oceanic fronts formed in the confluence region of two or more currents.

Therefore, in coastal mountain countries a systematic monitoring of terrestrial vegetation, snow covered areas and SST's could contribute a great deal to better

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management of natural resources and environmental assessment. Satellite borne systems are effective tools for accomplishing this task. A clear example of this application is the Advanced Very High Resolution Radiometer (AVHRR) of the United States National Oceanic and Atmospheric Administration (NOAA). Different papers have shown that the optical channels of this system are quite efficient in assessing and mapping vegetation, especially with the use of the Differential Normalized Vegetation Index (DNVI), which has proved to be highly correlated with vegetation parameters such as green-leaf biomass and green-leaf area.1/ In particular, Justice et al. demonstrate that the DNVI obtained from AVHRR data is related to green-leaf activity and as such provides an important tool by which to monitor vegetation phenology.2/ Imagery from the optical channel of the AVHRR can also be used to assess the extent of snow cover on a regional scale. On the other hand, the AVHRR thermal channel data, when properly handled, can provide SST with an accuracy of 0.5-1.0 C which is useful for climatological and oceanographic studies.3/ This channel can also be very useful for detecting pixels with high and low temperatures, such as the ones corresponding to forest fires, volcanic eruptions and frost.

In the present paper the contribution of AVHRR data for resource management, environmental assessment and global change studies in the southern region of South America is discussed. First, a brief description of the NOAA-AVHRR satellite system is presented. Then, the main characteristics of vegetation distribution, geomorphology and surrounding ocean currents over this region are presented. Finally, projects currently in progress related to land and oceanic environment are discussed. The use of this type of satellite data for disaster monitoring and mitigation is also described using some examples.

CHARACTERISTICS OF THE NOAA-AVHRR SYSTEM AND DATA

The NOAA satellites cross the equator at 3:30 and 15:30 (local time) for odd numbers of the NOAA series and at 7:30 and 19:30 for the even ones. Two daily images are obtained which are more adequate than other systems such as Landsat MSS with a coverage frequency of nine days with two satellites. In this way it is possible to obtain useful information even in frequently overcast areas. It is also possible to obtain composite images of the same region for different days. This requires the implementation of algorithms to eliminate cloudy pixels and being able to select from a series of daily images, which is the best value for a given pixel. As the number of orbits per day is not an integer, the sub-orbital tracks are not repeated on a daily basis. Therefore the same scene is viewed in consecutive days from different angles. As a consequence, geometric corrections are required for image comparison or/and superposition.

The maximum scanning angle of the AVHRR system is + 55.4 with a possible 2500 km swath. This is a great advantage because it makes possible the observation of large areas, but it also introduces anomalies which cannot always be resolved such as

the geometric and atmospheric distortions of the scan edges. Even though the resolution of 1.1 km compares poorly with that of Landsat-MSS, the AVHRR has proved to be very useful in the study of large areas and correlation with those sensors gives good results.4/ The dynamic range is larger than that of the MSS and it is not so easily saturated by snow or cloud reflectance. The radiometric sensitivity is also much better than that of MSS, which makes it possible to detect small changes in intensity not observed by other systems.5/ The spatial resolution of AVHRR data does not allow for small area assessment. However, the twice-a-day views provide a day time and night time look of cloud free areas on a regional scale.

A mathematical combination of channels 1 and 2 of either LAC (Local Area Coverage, 1.1 km resolution) or GAC (Global Area Coverage, 4 km resolution) data can be used to obtain vegetation indices. The Difference Normalized Vegetation Index (DNVI = channel 2-channel 1/channel 2 + channel 1) is preferred for global vegetation monitoring because it partially compensates for changing illumination conditions, surface slope, and viewing aspects. Since 1982, GAC data from NOAA has been used by the National Environmental Satellite Data and Information Service (NESDIS) to generate vegetation indices in a Global Scale (GVI). Daily arrays are composited over a seven day period by saving the maximum vegetation index calculated for each array location over the composite period.

MAIN ENVIRONMENTAL CHARACTERISTICS OF THE REGION AND SOME PROJECTS PRESENTLY IN PROGRESS USING AVHHR-DATA

The area (20 S-56 S, 40 W-8O W) covers the southern South American continental region, a portion of the South Atlantic Ocean and a narrow band of the South Pacific Ocean. The main environmental characteristics of this region are presented in the following paragraphs.

South America's natural vegetation may be classified in ten main units:
1) wet evergreen tropical forests,
2) deciduous tropical forests,
3) tropical coastal marshes,
4) tropical savannas,
5) tropical Andean mountain forests,
6) temperate forests,
7) natural temperate grassland,
8) semiarid formations,
9) arid formations, and
10) alpine and subalpine formation.

Only units 1 and 3 are not present in the area chosen; therefore a large variety of vegetative formation, arid, semiarid, tropical and alpine, can be observed. Furthermore, each unit can be divided into subunits.6/ The arid and semiarid formations are the

largest and cover most parts of Argentina and a portion of Chile, Bolivia and Paraguay. The subalpine and alpine formations are the smallest ones and they are spread throughout Chile, Bolivia, Argentina and Brazil.

The Southern Andes, 3200 km long, are fairly heterogeneous, both from a geologic and physiognomic point of view. The region lies south of a line that runs roughly from Antofagasta, Chile, on the Pacific Ocean, to slightly north of Tucuman, Argentina, south of Cordoba and then along the foothills of the mountains to Tierra del Fuego. From north to south the magnitude of the principal mountains declines. The cordillera is doted with volcanoes, many of them active. The Southern Andes are characterized by a seasonally dry climate except south of latitude 40 S where humid westerly storms are predominant.

The South Atlantic and South Pacific Oceans are characterized by four important currents: the Peru, Cape Horn, Brazil and Malvinas currents. The Peru current is narrow, fairly stable and flows northward close to the South American Pacific coast; it roughly parallels the coastline, beginning at 40 South and flows past Chile, Peru and Ecuador to the southwest end of Colombia. The Cape Horn current sets continuously eastward close to the tip of South America and enters the Drake passage at about 70 W. The Brazil current is an extension of the Atlantic South Equatorial current which divides between latitudes 7 S and 17 S, depending on the time of the year, and flows southwest parallel to the Brazilian coast. The Malvinas current originates mainly from the Cape Horn current in the northern part of the Drake Passage. After passing through the strait, the current sets north between the continent and the Malvinas (Falklands) Islands and follows the coast of South America until it joins the Brazil current. The confluence of these two currents, situated near the entrance of the La Plata River estuary, is characterized by strong seasonal temperature changes and large spatial fluctuations at the border of the two currents. The geographic location of the currents' confluence is about 24 S in May-July and about 36 S in February. Also simple or multiple warm eddies, separated from the main water course of the Brazil current appear as far as 50 S. This generates an extensive mixing zone with multiple fronts. That is, the SST's over the Atlantic regions are strongly affected by the dynamics of these two currents exhibiting a very unstable behaviour.

There are three tracking antennas receiving AVHRR data that cover the area considered. They are located in Brazil, Chile and Argentina. The first one placed at C. Paulista, Sao Paulo, is administrated by Instituto de Pesquisas Espaciaies (INPE). The second one, managed by the Centro de Estudios Espaciales (CEE) at the Universidad de Chile, is located 40 kms from the city of Santiago. The third antenna is placed at Villa Ortuzar, in Buenos aires, and is managed by the Servicio Meteorologico Nacional (SMN). The images recorded by the INPE antenna are used in different projects, particularly to monitor crop productions using NDVI derived from AVHRR GAC data.7/ This NDVI is used to evaluate the crop growth conditions through its response to the use of water for the crop production regions in the Brazilian State of Sao Paulo. The

responsiveness of NDVI to water stress or rainfall is analyzed in order to identify the response time lag of NDVI in the regions studied. This information may help determine a suitable technique for separating the contribution of annual crop growth to cumulative NDVI from its background vegetation and hence, to improve the crop yield estimates. Thermal channel 3 of the AVHRR is used operationally for detection of fires.8/ Biomass burning associated mainly with agriculture, pasture renovation and deforestation is a common practice in Brazil which has significant environmental consequences, as detected by orbital remote sensing. An operational system is currently used to detect fires in dry seasons (June to November) by using band-3 thermal images and automatic daily processing in almost real time, for parks, forests and wildlife reserves.

Some important maps have been derived in Brazil from NOAA-AVHRR data and combined with other parameters for environmental studies. For example, NDVI maps of South America were produced as a climatic variable indicator to study the evolution of drought areas during six rainy seasons.9/ A combination of three geophysical land surface parameters deduced from AVHRR data, albedo, greenness and temperature, has been used to produce a monthly bio-climatic map over selected regions.10/ A large number of digital maps showing deforestation in southern Amazonia have also been compiled from AVHRR imagery and integrated with various cartographic dataplanes within a geographic information systems (GIS).11/

In Chile, the CEE processes sea surface temperature fields on a daily basis and this has provided significant contributions to the actual oceanographic knowledge of the Chilean sea.12/ This thermal imagery has shown different oceanic and coastal processes occurring along the coastline at different time scales. These images have contributed to the study of upwellings off the Chile coast, when and where they occur, its intensity, shape and time-scale and some of its consequences on marine life.13/ Furthermore, other oceanic processes have been monitored such as spiral eddies, oceanic fronts, local and oceanic currents.

The relationship between these oceanic processes and the different species of fish has been of special interest to researchers, particularly at the Universidad Catolica de Chile in Viña del Mar.14/ Nowadays the SST images are an important tool for the study of the environment of the different species and for the determination of areas of high probability of fish capture. It is advisable to point out that SST charts produced by the CEE are not only used by the important fishing fleets but also by non-industrial fishermen. Recently researchers have incorporated the use of AVHRR satellite information into the determination of adequate regions to develop new sea farms or to study the environmental conditions that have affected existing sea farms.15/

Snow accumulation during winter and spring is the main source of water during summer and autumn and is also used to produce electric power, irrigation and drinking water supplies in many Chilean regions. Therefore the use of NOAA-AVHRR data

supported by Landsat MSS to localize and estimate the extent of snow covered areas has been one of the activities developed by the CEE to collaborate in modelling the water production from snow accumulation.16/

Brightness temperature determined with the early morning passage are actually used to determine frost risk areas and the design of agrometeorological networks to mitigate its effects. A normalized vegetation index is used to monitor dynamic vegetation during the different seasons in wet and dry years and to classify land cover, grassland location and extent, and estimate crop acreage.17/

In Argentina the AVHRR data are used by the SMN in its own activities and are also provided to a large community of users for hydrological, land and oceanic studies.

Over the past eight years, AVHRR thermal channel information has been used to obtain a global picture of the sea surface temperature in the South Atlantic ocean and the way it changes seasonally.18/ Different studies have been conducted with these images in the La Plata River Estuary region, its oceanic front and the Malvinas-Brazil currents confluence, determining the spatial structure and temporal variability of the temperature field. Other oceanographic phenomena along the Argentine coast have been monitored such as the front induced by strong tidal currents off the Valdes Peninsula, essential to the ecological equilibrium of this important marine resource. Another oceanographic process studied using this satellite information has been the cold water coastal current that flows from the Magellan strait against the coast and into the San Jorge Gulf waters in the south of Argentina.

The NVI, combined with other satellite data, are used together with meteorological and hydrological parameters to monitor the temporal change of vegetation, to control and evaluate the cultivated land and estimate the crop acreage and biomass in the central region of Argentina, as well as to monitor and estimate the effects of floods on the same region and in the northeast of Argentina. In the same way this index contributes to the identification of active desertification processes in the Patagonia and to the formulation of a programme to control the progress of the process. There are currently some projects that plan to use vegetation indices to classify regional land cover/land use and to determine soil characteristics and urban growth.

The efficiency for observing volcanic eruptions, due to the coverage frequency of the NOAA-polar orbiting satellite, has been exploited to study a series of Hudson Volcano eruptions (latitude 46.10 S, longitude 72.55 W) which began on 8 August 1991. The five channels have been used to identify the vertical and horizontal plume morphology, track the trajectory of the ash cloud, monitor the eruption growth rate and calculate the plume altitude. In addition, the satellite data has been very useful in issuing warning to aircraft flying near the plume.

CONCLUSIONS

It has been shown that AVHRR data play an important role in obtaining environmental information on a regional scale. It has also been proven that these data can be an important component of evaluations of land-surface changes providing information on parameters which would be difficult to collect from the ground. Consequently, AVHRR data are critical for any regional spatial/temporal study of the southern portion of South America, and also for the contribution to any global change study related to this region.

However, it should be emphasized that satellite measurements are neither absolutely homogenous nor are they consistent, adequately sophisticated, accurate direct measurements of terrestrial or oceanic phenomena as to be the sole source of information for critical studies. For this and other reasons, satellite measurements are not a substitute for *in situ* measurements.

In the past (and still too often in the present) scientists have looked at satellite imagery using sophisticated image processing systems, and have looked at other data using paper plots or computer terminals, without being able to perform multivariate analysis or integration of the data. We can now derive maximum benefits from modern data systems obtained through other sources when they are combined into information systems designed for such multivariate spatial (and in many cases temporal) analysis. Such Geographic Information Systems (GIS) can facilitate the optimization into sophisticated multivariate models of environmental phenomena or processes.

As it has been shown, AVHRR data have been found very useful in Brazil, Chile and Argentina, but primarily for these countries' domestic benefit. Although the techniques and methodologies used and, in many cases, the objectives are similar, there are not any joint projects among these countries. It would be very profitable for them and the other countries of the region (Uruguay, Paraguay and Bolivia) to build a common AVHRR database, integrated into a regional GIS with those of other sources. This could not only give rise to major efforts for developing resources, but it could also assist efforts to protect and preserve resources from destructive human activity. Such a project could, later on, be extended, with all its benefits, to all of Latin America being integrated to some international projects, such as the Global Change Database.19/

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